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REPORT OF THE INTERNATIONAL ICE PATROL SERVICE IN THE NORTH ATL--ETC (U)

APR 78 H G KETCHEN, C W JENNINGS

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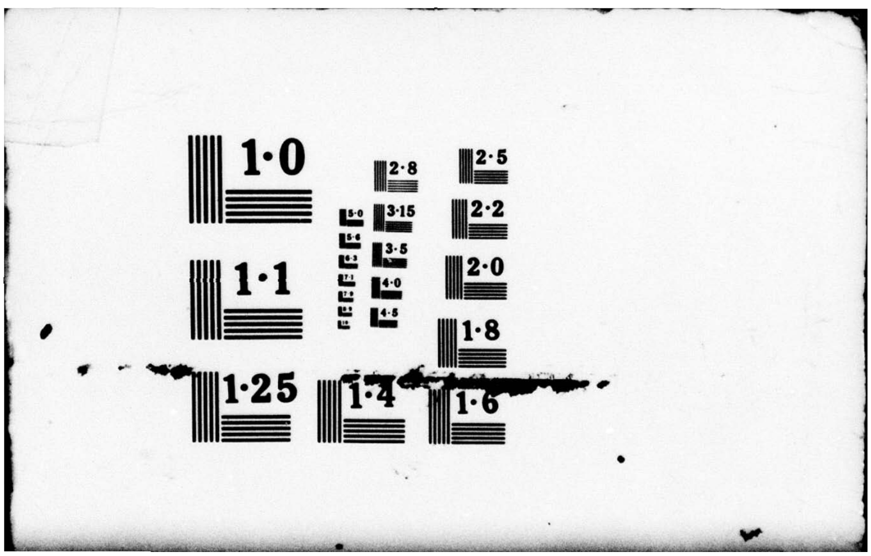
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LEVEL II

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SEASON OF 1976

CG-188-31

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16. Abstract

This report contains information on Ice Patrol organization, communications and operations, on ice and environmental conditions and their interaction as observed during 1976, and on various Ice Patrol research efforts.

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6 REPORT OF THE INTERNATIONAL ICE PATROL SERVICE
IN THE NORTH ATLANTIC OCEAN.

Season of 1976,

CG-188-31

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FOREWORD

Forwarded herewith is Bulletin No. 62 of the International Ice Patrol describing the Patrol's services, and ice observations and conditions during the 1976 season.

11 15 Apr 78

N. C. VENZKE
Chief, Office of Operations

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PREFACE

This report is the 62nd in a series of annual reports on the International Ice Patrol Service in the North Atlantic Ocean. It contains information on Ice Patrol organization, communications and operations, on ice and environmental conditions and their interaction as observed during 1976, and on various Ice Patrol research efforts.

The authors of this report, Lieutenant H. Gregory KETCHEN, USCG and Marine Science Technician First Class Charles W. JENNINGS, USCG acknowledge the Canadian Department of the Environment for providing ice and weather information, the United States Weather service for weather updates, the United States Naval Weather Service for both weather and oceanographic products, and the United States Coast Guard Oceanographic Unit and Cutter EVERGREEN for oceanographic data collected during the course of the ice season. Acknowledgement is also made to Yeoman Second Class Terry L. GEST, USCG and Marine Science Technician Chief Neil O. TIBAYAN, USCG for their assistance in the typing and preparation of the majority of illustrations in this report.

INTERNATIONAL ICE PATROL, 1976

The 1976 International Ice Patrol Service in the North Atlantic Ocean was conducted by the personnel and with the facilities of the United States Coast Guard under the provisions of Title 46, United States Code, Sections 738, 738a through 738d and the International Convention for the Safety of Life at Sea, 1960, Regulations 5 through 8. The International Ice Patrol provides a service that observes and disseminates information on ice conditions in the Grand Banks Region of the Northwest Atlantic Ocean. During the ice season, the southeastern, southern and southwestern limits of the regions of icebergs in the vicinity of the Grand Banks of Newfoundland are guarded for the purpose of informing passing ships of the extent of this dangerous region. The International Ice Patrol also studies ice conditions in general with emphasis on the formation, drift and deterioration of icebergs, and assists ships and personnel requiring aid within the limits of operation of the Ice Patrol forces.

The International Ice Patrol is directed from the Ice Patrol Office located at the U.S. Coast Guard Base, Governors Island, New York. The Office gathers ice and environmental data from a variety of sources, maintains an ice plot, forecasts ice condition, prepares the twice-daily Ice Bulletin, replies to requests for special ice information, and executes operational control of the Aerial Ice Reconnaissance Detachment, the Ice Patrol oceanographic cutter(s), and the Surface Patrol cutter(s) when assigned.

Vice Admiral William F. REA, U.S. Coast Guard, was Commander, International Ice Patrol. Commander Albert D. SUPER, U.S. Coast Guard, was the Ice Patrol Officer and as such directly responsible for the management of the Patrol.

There were two preseason reconnaissance missions conducted during the periods 22 January to 1 February and 25 February to 10 March 1976. The Aerial Ice Reconnaissance Detachment was deployed to St. John's, Newfoundland, Canada on 18 March 1976 and returned to the United States on 22 July 1976.

The 1976 Ice Season officially commenced at 0000 GMT on 18 March, when the first Ice Bulletin was issued, and continued until the final Bulletin was issued at 0000 GMT 22 July 1976. Daily facsimile charts and twice-daily Ice Bulletins were prepared by the International Ice Patrol and broadcast as discussed in the communications section of this report. Iceberg information was also included on the regularly scheduled radio facsimile broadcasts made by the Navy Weather Central Norfolk/NFAX, Maritime Command Radio Halifax/CFH, Radio Bracknell/GFE, Radio Hamburg-Quickborn/DGC and Radio Quickborn/DGN.

The U.S. Coast Guard Cutter EVERGREEN, commanded by Lieutenant Commander Joseph H. DISCENZA, U.S. Coast Guard conducted oceanographic cruises for the Ice Patrol from 23 March to 25 April and 18 May to 01 July. Additionally, the U.S. Coast Guard Cutter SHERMAN, commanded by Captain Howard M. VEILLETTE conducted a special Ice Patrol oceanographic cruise slightly east of the Grand Banks from 08 June–01 July 1976. All these cruises provided vital ocean current and temperature data used as inputs to the computerized iceberg drift program and iceberg deterioration predictions. Ice Patrol oceanographic activities are discussed further in the Oceanographic Conditions section of this report.

For the third consecutive year no surface patrol was required to patrol the southern limits of icebergs.

During the 1976 Season an estimated 151 icebergs drifted south of 48° North latitude, a light season that had a total duration of 126 days.

AERIAL ICE RECONNAISSANCE

During the period 22 January 1976 to 22 July 1976, a total of 75 ice observation flights were flown. Preseason flights made in January and February accounted for 14 flights, and the remaining 61 flights were made during the ice season. There were no post-season flights. The purpose of the preseason surveys was to determine the inventory of icebergs in the western Labrador Sea and Davis Straits for use in an attempt to predict the severity of the 1976 ice season. The objectives of the regular season flights were to locate the southwestern, southern, and southeastern limits of icebergs, to determine the iceberg population north of these limits in the vicinity of the Grand Banks and occasionally along the Labrador Coast, and to determine sea surface temperatures along search tracks using an airborne radiation thermometer. In addition to this routine reconnaissance flights, there were 10 flights conducted solely for the purpose of testing and evaluating a Side-Looking Airborne Radar (SLAR) System. It is anticipated that this system will become an invaluable tool to the Ice Patrol for the all weather detection and identification of icebergs.

Table 1—Aerial Ice Reconnaissance Statistics September 1975 to August 1976

Month	*Number of Flights*	*Flight Hours*
PRESEASON		
September-December	0	0
January	4	25.8
February	3	14.2
March	7	40.7
Preseason total	14	80.7
SEASON		
March	5	28.8
April	11	59.2
May	19	100.8
June	14	74.6
July	15	68.1
August	0	0
Season total	64	331.5
Remote Sensing Test and Evaluation		
April	0	0
May	9	43.8
June	1	6.8
July	0	0
T&E total	10	50.6
Season total	74	382.1
Annual total	88	462.8

In addition, 51 missions and 216.1 flight hours were employed in penetrometer tagging R&D, a media-public affairs reconnaissance deployment, special parts/logistics support deployments, and periodic flights between St. John's and the United States necessary for crew relief and aircraft maintenance.

Aerial ice reconnaissance was accomplished by U.S. Coast Guard HC-130 (Lockheed Hercules) four-engine aircraft from the Coast Guard Air Station in Elizabeth City, North Carolina. The aircraft used on Ice Patrol were outfitted with inertial navigation systems (INS) with position accuracy of better than ±5 nautical miles. During the iceberg season, the aircraft operated out of Innotech Aviation at Torbay Airport, St. John's, Newfoundland.

COMMUNICATIONS

Ice Patrol communications included receiving reports of ice, sea surface temperature, and other environmental conditions, transmitting twice-daily Ice Bulletins and a daily facsimile chart, and the administrative and operational traffic necessary to the proper conduct of the Patrol. The Ice Bulletin was transmitted by teletype from the Ice Patrol office in New York twice each day to our 30 addresses, including those radio stations which broadcast the Bulletin. These stations were U.S. Coast Guard Communications Station Boston/NMF/NIK, Canadian Coast Guard Radio Station St. John's/VON. Canadian Forces Maritime Command Radio Station Mill Cove/CFH, and on the U.S. Navy LCMP Broadcasts from Norfolk, Virginia; Londonderry, Northern Ireland; Thurso, Scotland; and Keflavik, Iceland. The daily radiofacsimile ice chart was broadcast from the Ice Patrol offices in New York via a transmission line direct to transmitters at U.S. Coast Guard Communications Station Boston/NIK.

Coast Guard Communications Station Boston transmitted the Bulletin by CW (Morse Code). A 2-minute series of test signals, the transmissions were made at 25 words per minute and then repeated at 15 words per minute. Table 2 lists frequencies and times of broadcasts used at the various radio stations for the Ice Patrol Bulletin:

Special broadcasts were made by Canadian Coast Guard Radio Station St. John's/VON and U.S. Coast Guard Communications Station Boston/NIK as required when icebergs were sighted outside the limits of ice between regularly scheduled broadcasts. These transmissions were preceded by the international safety signal (TTT) on 500 kHz.

Merchant ships calling to report ice sightings, weather and sea surface temperature to the Ice Patrol were requested to contact U.S. Coast Guard Communication Stations, Ocean Weather Station C7H and, if unable to work these stations, Canadian Coast Guard Radio Station St. John's/VON. These ships were requested to use the regularly assigned international call sign of the station being called; however, Coast Guard stations were alerted to answer NIK or NIDK calls if used.

Ice information services for the Gulf of St. Lawrence, as well as the approaches and coastal waters of Newfoundland and Labrador, were provided by the Canadian Ministry of Transport from December until approximately late June. Ships obtained ice information by contacting Ice

Radio Station	Time of Broadcast (GMT)	Frequencies (kHz)
CW Broadcasts:		
Coast Guard Communications Station Boston/NIK	0018 1218	5320, 8502. 8502, 12780.
Coastal Radio St. John's/VON	0000 and 1330	478.
Maritime Command Radio Mill Cove/CFH	0130 and 1330	426 (off second Thursday each month from 1200-1600 GMT), 4255, 6430, 12880, 16886.5 and 22397.5.
Naval COMMSTA Londonderry (LCMP BCST) Naval COMMSTA Iceland Naval COMMSTA Norfolk	0500 and 1700	5870, 8090, 12125, 16180, 20625, 25590 (Note: 20625 and 25590 activated only 1200-2400 (GMT)
Radiofacsimile Broadcasts:		
Coast Guard Communications Station Boston/NIK	1600	8502, 12750 (drum speed 120)
Fleet Weather Central Norfolk (NFAX)	0805 and 1805	3357, (0001-1200 GMT), 4975, 8080, 10865, 16410 (1200-2400 GMT), and 20015. (Limits of all known ice on nephanalysis.)
CANMARCOM/CFH	0000 and 1200	4271, 9890, 12510, 17560 (drum speed 120). (Primarily sea ice in Gulf of St. Lawrence and North. Limits of icebergs sometimes given.)
Radio Bracknell/GFE	1400	4782, 9203, 14436, or 18261 (drum speed 120) (N. Atlantic Ice Obs.)
Radio Hamburg-Quickborn/Pinneburg/DGC, DGN	0906 (Except Sundays and Holidays) and 2145	3855.8 (0905-1014 GMT) and 13657.1 (2100-2157 GMT) (drum speed 120). (Ice Conditions in West Atlantic.)
Special Broadcasts:		
Coastal Radio St. Johns/VON	As required when icebergs are sighted outside the limits of ice between regularly scheduled broadcasts.	Preceded by International Safety Signal (TTT) on 500 kHz

TABLE 2

Operations Officer, Dartmouth, Nova Scotia via any east coast Canadian Coast Guard Radio Station.

Communications Statistics for the period 1 September 1975 to 31 August 1976 are shown below in Table 3.

TABLE 3—Communications Statistics

Number of ice reports received from ships	312
Number of ships furnishing ice reports	87
Number of ice reports received from commercial aircraft	2
Number of sea surface temperature reports	1,813
Number of ships furnishing sea surface temperature reports	47
Number of ships requesting special ice information	3
Number of NIK Ice Bulletins issued	253
Number of NIK facsimile broadcasts	126

Of the ships furnishing Ice Patrol with special sea surface temperature observations, the eight most outstanding contributors were:

M/V BAKKAFOSS/TFXQ

M/V ATLANTIC SPAN/SLPN (5th consecutive year)

M/V ESKDALEGATE/GUIC

M/V MONTROYAL/SFHN

HMCS NIPIGON/CGZP

M/V C P TRADER/GNAR

M/V MANCHESTER CONCORDE/GYUX

M/V BRUNSWICK/DGBI

ICE CONDITIONS, 1976 SEASON

September-December, 1975

After the close of the 1975 Ice Patrol Season, occasional icebergs continued to drift south along the Labrador coast, but none of these survived long enough to reach the primary North Atlantic shipping lanes. Ice reports received during the latter part of September included the sighting of a concentration of icebergs along a line from 53°N, 52°W to 51°N, 49°W. During this same period, a Canadian ice reconnaissance aircraft reported sighting a total of 117 icebergs and 135 growlers along the north side of Hudson Strait between Resolute Island and Big Island. On 26 September, two icebergs were sighted drifting together in an anomalous area (i.e., 53°06′N, 41°40′W). This location is far from the normal iceberg limit. These bergs were apparently the remaining pieces of one or possibly two large icebergs forced east out of the mainstream off Labrador by strong offshore winds that persisted over this area from mid-July through September. On September 27, a group of three icebergs was sighted in the vicinity of 50°54′N, 53°24′W. This was the last ice received until late October. Between mid-August and mid-October the eastern Canadian waters remained free of sea ice from the Baffin Island coast southward. Several iceberg reports were received from merchant shipping in the latter part of October. The southernmost of these was a medium size iceberg in position 50°45′N, 54°05′W on October 31. Freeze-up started in northern Baffin Bay during October and advanced to 68°N by the end of the month. On November 19, aircraft returning from Europe at high altitude reported a very large iceberg, estimated to have a horizontal area of approximately 3 square miles. This sighting was not confirmed and could possibly have been a small very dense fog patch. This was the only berg report for the month. During December, sea ice cover grew rapidly, expanding from the northern tip of Labrador in the beginning of the month to reach Newfoundland's northern peninsula by month's end. This pushed season freeze-up approximately one week to ten days ahead of normal. New ice was beginning to form in some of the sheltered shallows of Notre Dame Bay and the northern Newfoundland peninsula. Fast ice had formed along the entire east coast of Labrador and close pack new and grey ice from this area drifted southward across the eastern approaches to the Strait of Belle Isle. Reports of ice from trans-Atlantic shipping proceedings through the Strait of Belle Isle during December indicated a few icebergs were beginning to drift into this area.

January 1976

A Canadian forces aircraft reported three icebergs (no size indicated) at position 53°25′N, 52°33′W on 27 January. This was the only report during the month. After a brief warming trend at the beginning of the month, very cold air persisted over the Canadian Atlantic provinces until mid-January. As a result, there was widespread growth of new ice northeast of Newfoundland. Between 25 and 31 January, preseason flights were made along the Labrador coast, across Davis Strait and up the Baffin Island coast to Cape Dyer (Figure 1). The latitudinal iceberg distribution observed during these flights is illustrated graphically in figure 2. The count north of Hudson Strait in the survey area was 516, about 80% of the previous 10 year average. The iceberg inventory south of Hudson Strait was 42 or 55% of the average. The icebergs sighted were generally smaller than normal. The southernmost of these were one medium and two small bergs first sighted on 25 January in the vicinity of 53°51′N. These were resighted on 31 January in positions 53°21′N, 51°16′W and 53°18′N, 51°40′W. Strong winds and above normal temperatures during the last half of January retarded the southward drift of the sea ice pack off Labrador, causing it to expand seaward and to maintain generally light ice conditions in Notre Dame Bay. By the end of January, the sea ice

cover had advanced to a southern limit approximately by a line from 61°N 60°W southeasterly to 51°30'N, 50°W then southeasterly to Notre Dame Bay.

February 1976

With the southernmost icebergs still well north of the major shipping lanes, only one report was received from merchant shipping in February. Although this report of a small iceberg in position 51°10'N, 46°20'W on February 22 was the southernmost for the month, the iceberg limit established in early March indicated that bergs had reached at least 50°N by the end of February. Cold and persistent northwesterly winds across Davis Strait and in the northern Labrador Sea resulted in an abnormally extensive ice cover in this area. The heavier sea ice served to better protect those icebergs that would be reaching the Grand Banks late in the season. Off Newfoundland, the windflow continued to spread pack ice eastward, extending to nearly 49°W between 50° and 51°W by mid month. By month's end, the ice pack reached some 200 miles east of St. John's and south to 46°45'N. To the southwest of Newfoundland, pack ice was flowing out of the Gulf of St. Lawrence through the Cabot Strait and had extended approximately 100 miles east of Sydney.

March 1976

The second series of preseason flights were completed between February 27 and March 10. Tracks flown and icebergs observed during these reconnaissance flights are shown in figure 3. The latitudinal distribution of observed icebergs is displayed graphically in figure 4. When adjusted for poor visual and radar coverage in certain areas due to adverse weather, these counts represent roughly 50% of the normal upstream iceberg population for that time of year. As in January, the icebergs were predominantly small or medium sized with only a few large bergs observed. A total of 98 medium and large size icebergs were sighted between 55°N and 65°N. The southernmost iceberg spotted was a small tabular at 47°45'N, 46°00'W, which was predicted to have crossed 48°N on 9 March and was the first iceberg to reach that latitude in 1976. By mid-March, new and grey ice predominated in the coastal waters from Cape St. Francis northward. The heavy pack ice was east of Belle Isle and 60 miles east of Capes Freel and St. Francis. The eastern limit of ice had almost reached Flemish Cap. On approximately 12 March, the sea ice reached its southernmost extent for 1976 at latitude 45°55'N southeast of Cape Race. Based on predicted southward drifts of icebergs observed during the second preseason flight, the Ice Reconnaissance Detachment deployed to St. John's and the Ice Patrol season officially commenced on 18 March. Flights on 23, 24 and 27 March (Figure 5) established the southern and eastern limits of icebergs and growlers in the vicinity of the Grand Banks. It was estimated that 33 icebergs crossed 48°N during March. Although this equals the 30 year average for March, the predominant drift for the month was toward the east between 47°N and 50°N. All of the bergs that crossed 48°N during the month were predicted to have melted before reaching 47°30'N. The southernmost sighting was a small tabular at 47°45'N, 46°00'W on 10 March and the easternmost iceberg for both the month and the season was a small drydock sighted in position 48°16'N, 42°37'W on 24 March.

April 1976

During latter March and early April, mild weather caused the melt of the light ice which had made up the major ice cover along Newfoundland's east coast. This resulted in a pronounced northward retreat of the ice edge. By April 5 (Figure 6), the concentrated pack had retreated north of 50°N and west of 50°W with diffuse pack extending south to 48°20'N and east to 48°W. Aerial reconnaissance on April 12, 13 and 15 (Figure 7) located only one berg and three radar targets south of 49°N. To commemorate the 64th anniversary of the tragic loss of the RMS TITANTIC on April 15th, members of the International Ice Patrol dropped a memorial wreath near an iceberg on the Grand Banks. By mid-month, the southern limit of the pack ice was near 51°N with its eastern extension ending near 49°W. Although a few strips and patches of first year ice lay just off the North Peninsula coast and northern White Bay, the remainder of the Newfoundland east coast was essentially free of sea ice. Near the end of the month, prevailing northerly winds brought patches of ice into Notre Dame Bay, but in the process considerably reduced the seaward extent of the ice pack. These same winds brought a

very large grouping of icebergs into the core of the Labrador Current north of the Banks. Some 96 icebergs and 57 growlers were sighted between 48°30'N and 50°20'N during reconnaissance flights on April 18, 20 and 23 (Figure 8). These bergs were apparently east of the reconnaissance tracks flown during the second preseason mission. Some were sighted during early March flights (Figure 3), but most were east of visual and radar coverage and outside the sea ice, between 56°N and 59°N. In hindsight, it appears that these bergs were blown some 90 to 100 miles off the Labrador coast in late February just before the reconnaissance flights and then blown back into the protection of the sea ice during early March after the preseason tracks were flown. It was estimated that only 13 icebergs crossed 48°N during April. The southernmost of these was a medium size blocky sighted on April 4 at 46°24'N, 46°09'W, and the easternmost was a small dome on 4 April in position 48°47'N, 44°08'W.

May 1976

Flights on April 30 and May 1 and 2 located a heavy concentration of icebergs off the northeast corner of the Grand Banks extending southeastward to Flemish Cap (Figure 10). These bergs, plus some drifting in from the north, were resighted during flights on May 6, 8, 10, 12, and 13 (Figures 11 and 12). Due to prevailing westerly winds, they had drifted east passing north of Flemish Cap. The easternmost iceberg for the month was a medium drydock sighted on May 10 in position 48°07'N, 43°27'W. On 24 May a growler was sighted further east at 46°37'N, 43°17' W(Figure 14). By mid-May, an open water route existed through the Strait of Belle Isle. Very open to close pack first year ice extended southward to about 51°N but remained approximately 30 miles east of Newfoundland's Northern Peninsula. The southernmost iceberg of the month was sighted with two other bergs and three growlers on May 30 at 44°10'N, 48°49'W. An estimated 67 icebergs crossed 48°N during May.

June 1976

Observation flights on May 31 and June 5 and 6 (Figure 15) revealed a diminishing iceberg population. Small groups of bergs and growlers were observed scattered just north of the Banks and east to Flemish Cap and others along 45°N east of the Banks. In June, warming air and sea temperatures brought a rapid disintegration of both pack ice and icebergs. By mid-June there was no sea ice south of 52°N. Flights on June 12 and 14 located only 17 icebergs and 12 growlers, none east of 46°30'W or south of 44°30'N (Figure 17). By June 22, those bergs off the northeast corner of the Grand Banks had drifted south to between 45°20'N and 46°20'N. One iceberg surviving from the group sighted east of the Banks on June 14 had drifted to a position slightly southeast of Flemish Cap by June 23 (Figure 19). All these icebergs had undergone extensive deterioration since their previous sighting. On June 29 the passenger liner Queen Elizabeth II spotted two groups of growlers, one at 43°30'N, 48°38'W and one at 43°30'N, 48°36'W. Two other merchant ships reported four icebergs and a number of growlers on the same day about 25 miles north of the QEII sightings. Predicted positions of this ice are shown in figure 20. This was the same ice that was spotted on June 22 (Figure 19) but was in final stages of decay. These reports were the southernmost for the month. Also on 29 June, a TWA flight returning from Europe spotted a medium sized berg at 46°36'N, 43°22'W. An estimated 35 icebergs crossed 48°N during the month.

July 1976

Flights on July 8 (Figure 21) spotted a small iceberg with a growler at 43°41'N, 48°58'W. This was believed to be the last ice presenting any danger to trans-Atlantic shipping during 1976. These two pieces of ice were resighted again by a merchant vessel on July 12 in position 42°28'N, 48°39'W. This was the southernmost ice sighting reported in 1976. Heavy fog persisted over the Grand Banks for most of July. Although the iceberg at the Tail of the Banks was predicted to have melted by July 15, this could not be visually confirmed due to the fog and the season was continued for an additional week. On July 22, feeling confident that the southernmost iceberg had totally melted, Ice Patrol advised the maritime community that there were no known icebergs south of 49°N and none expected to drift south of 47°N during the remainder of 1976. Ice Patrol services were terminated and the Ice Reconnaissance Detachment returned from St. John's on that date.

August 1976

No more icebergs were known to have drifted south of 48°N during August. The total count of icebergs crossing 48°N for the 1976 Season was 151. Although a number of sightings continued to be reported to the Ice Patrol during the month, all reports were located in the waters off Labrador. During August the only sea ice known to exist was off Baffin Island north of 62°N.

ESTIMATED NUMBER OF ICEBERGS SOUTH OF LATITUDE 48N, SEASON 1976

	Sept	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Total*
1976	0	0	0	0	0	0	33	13	67	35	3	0	151
TOTAL 1946–1976	10	2	4	11	64	261	1068	2939	2897	1751	483	100	9,590
AVERAGE 1946–1976	0	0	0	0	2	8	34	95	93	56	16	3	309
TOTAL 1900–1976	256	109	110	91	184	712	3170	7784	9980	5269	1679	489	29,833
AVERAGE 1900–1976	3	1	1	1	2	9	41	101	130	68	22	6	387

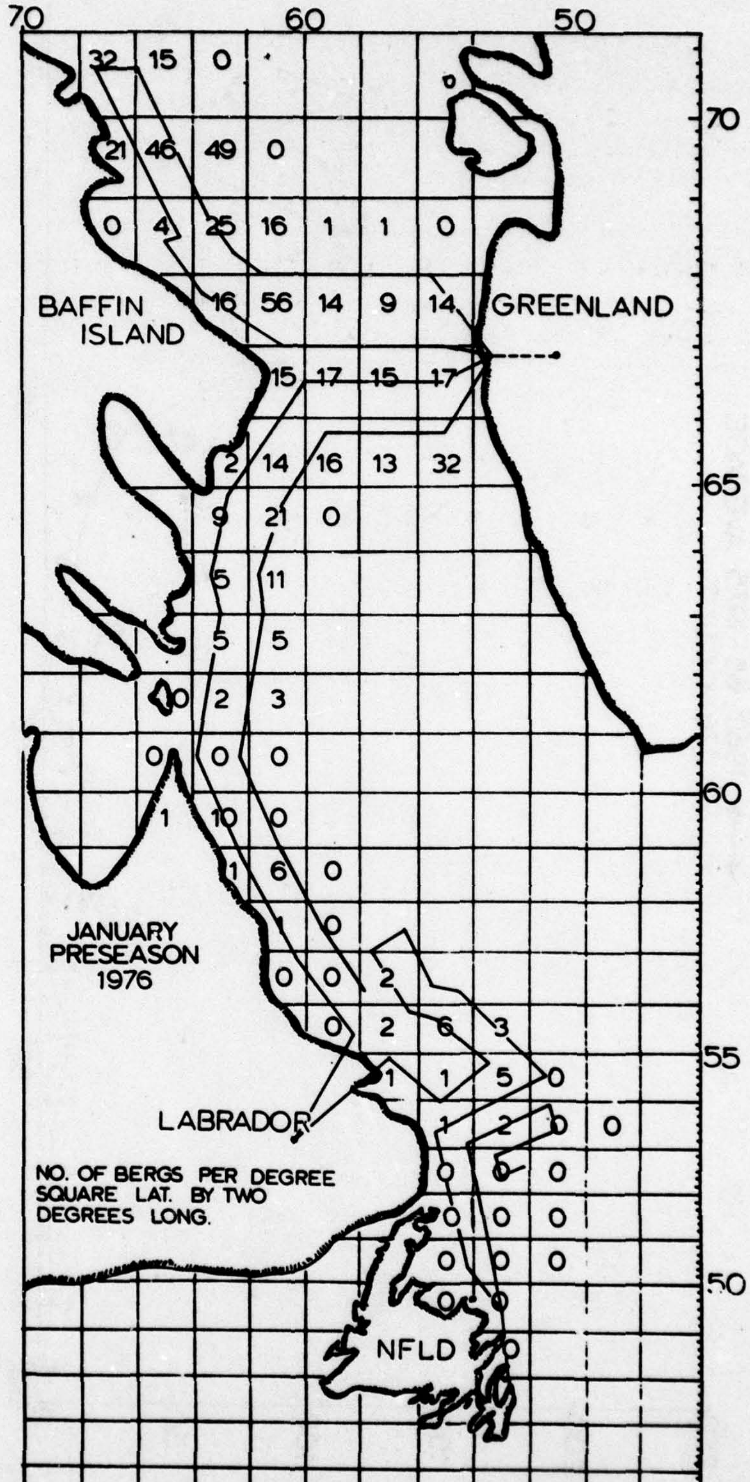


Figure 1.—Preseason Iceberg Survey, 1976

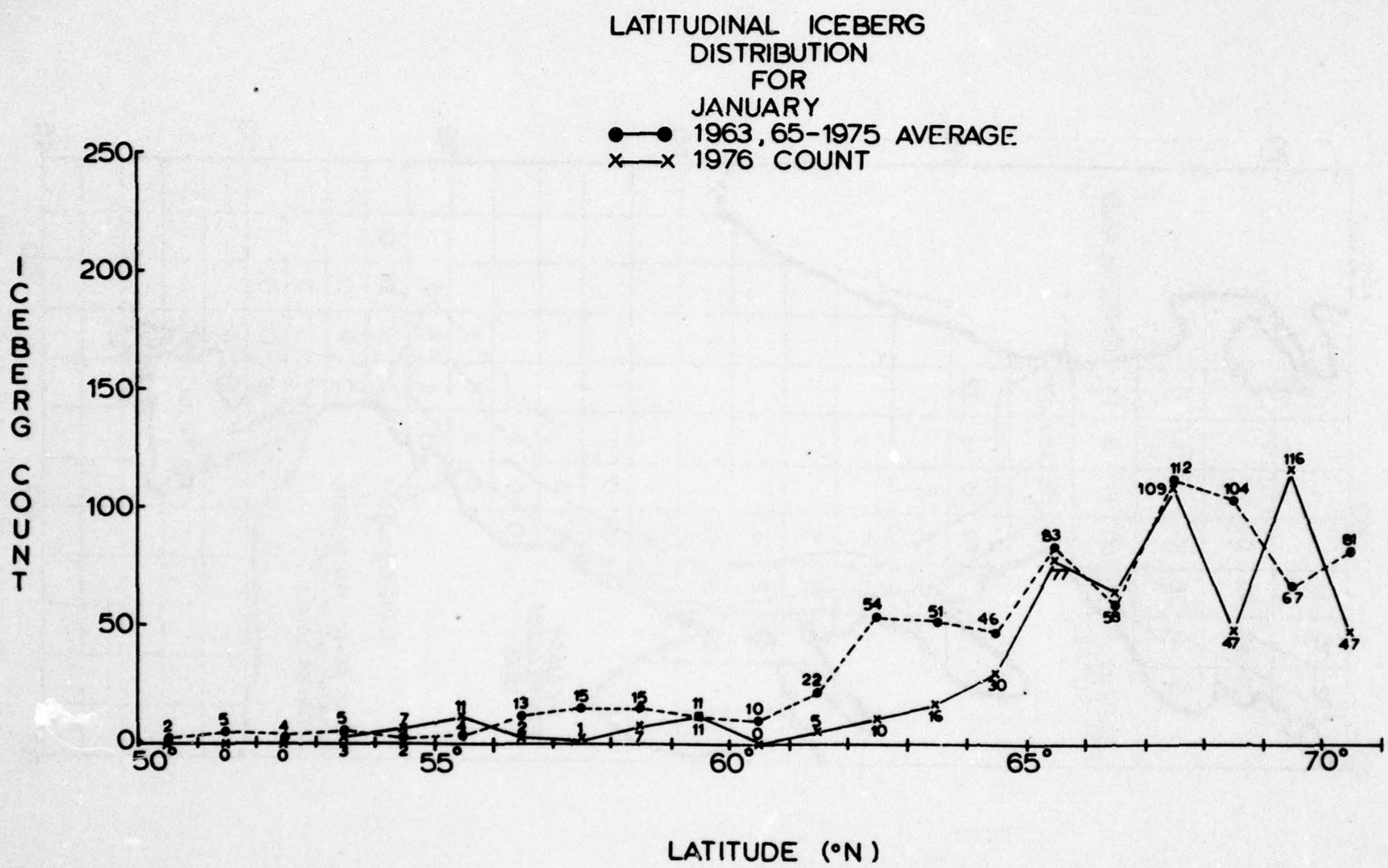


Figure 2.—Latitudinal Iceberg Distribution. January Preseason Survey

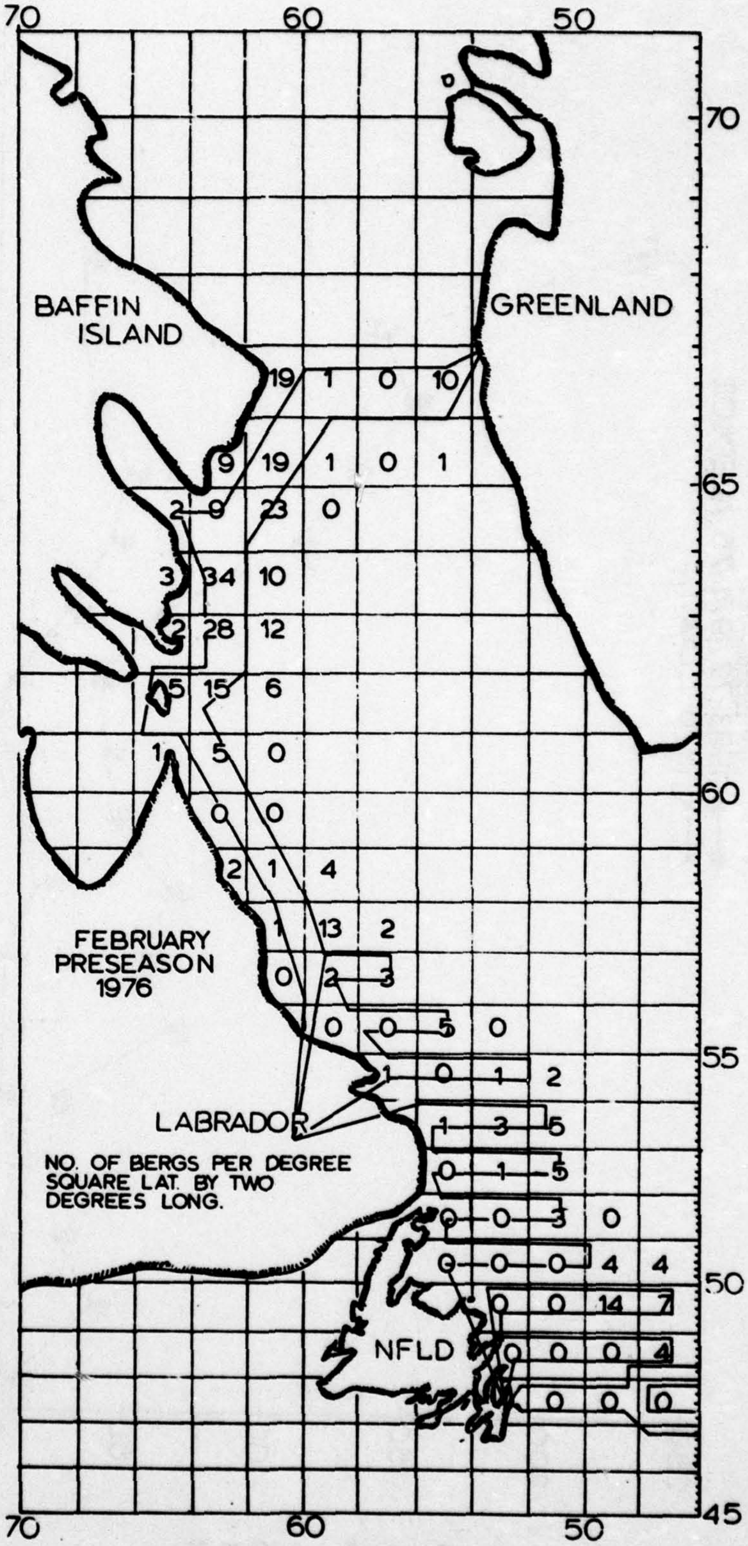


FIGURE 3.—Preseason Iceberg Survey, 1976

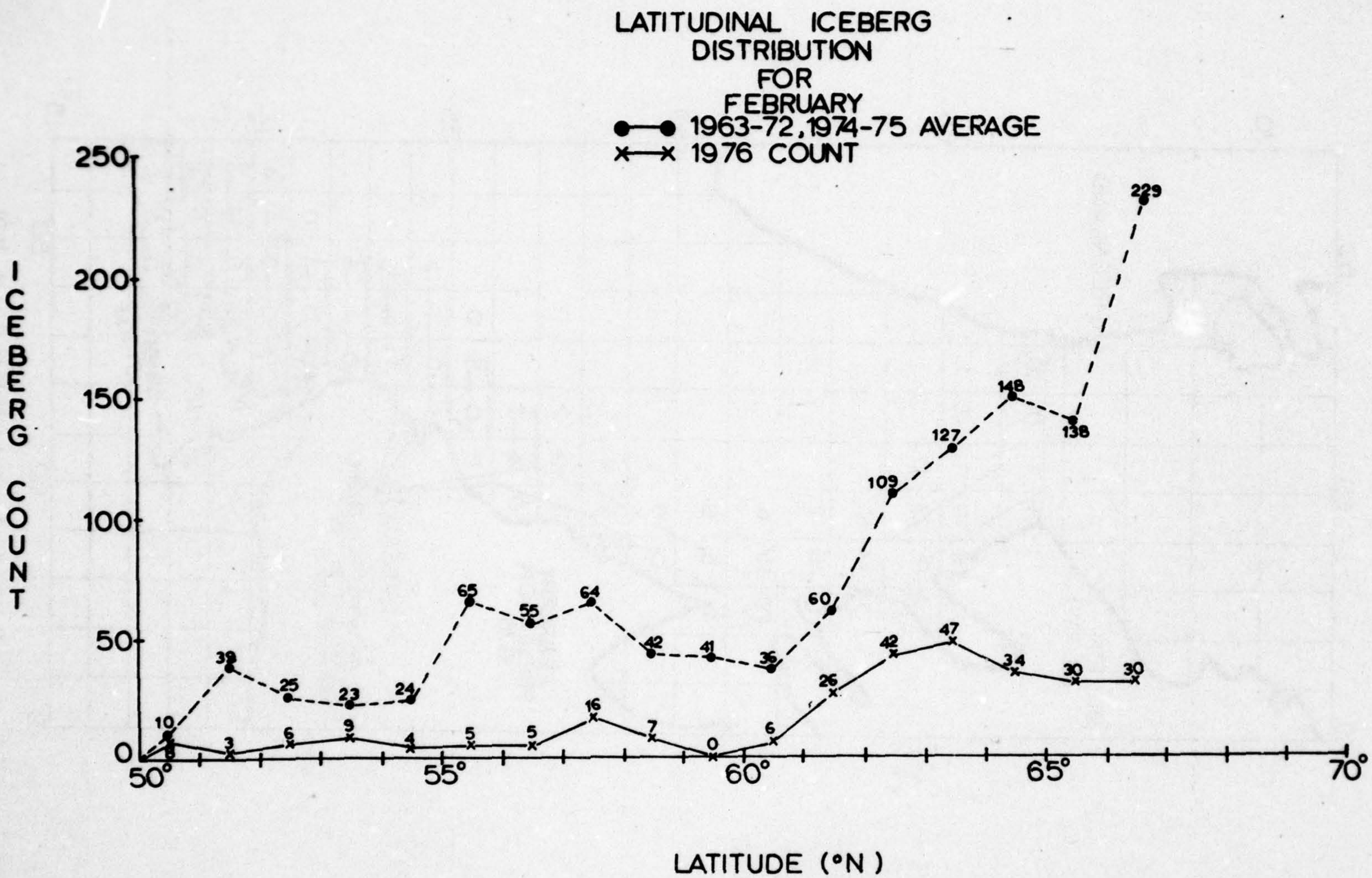


FIGURE 4.—Latitudinal Iceberg Distribution, February Preseason Survey

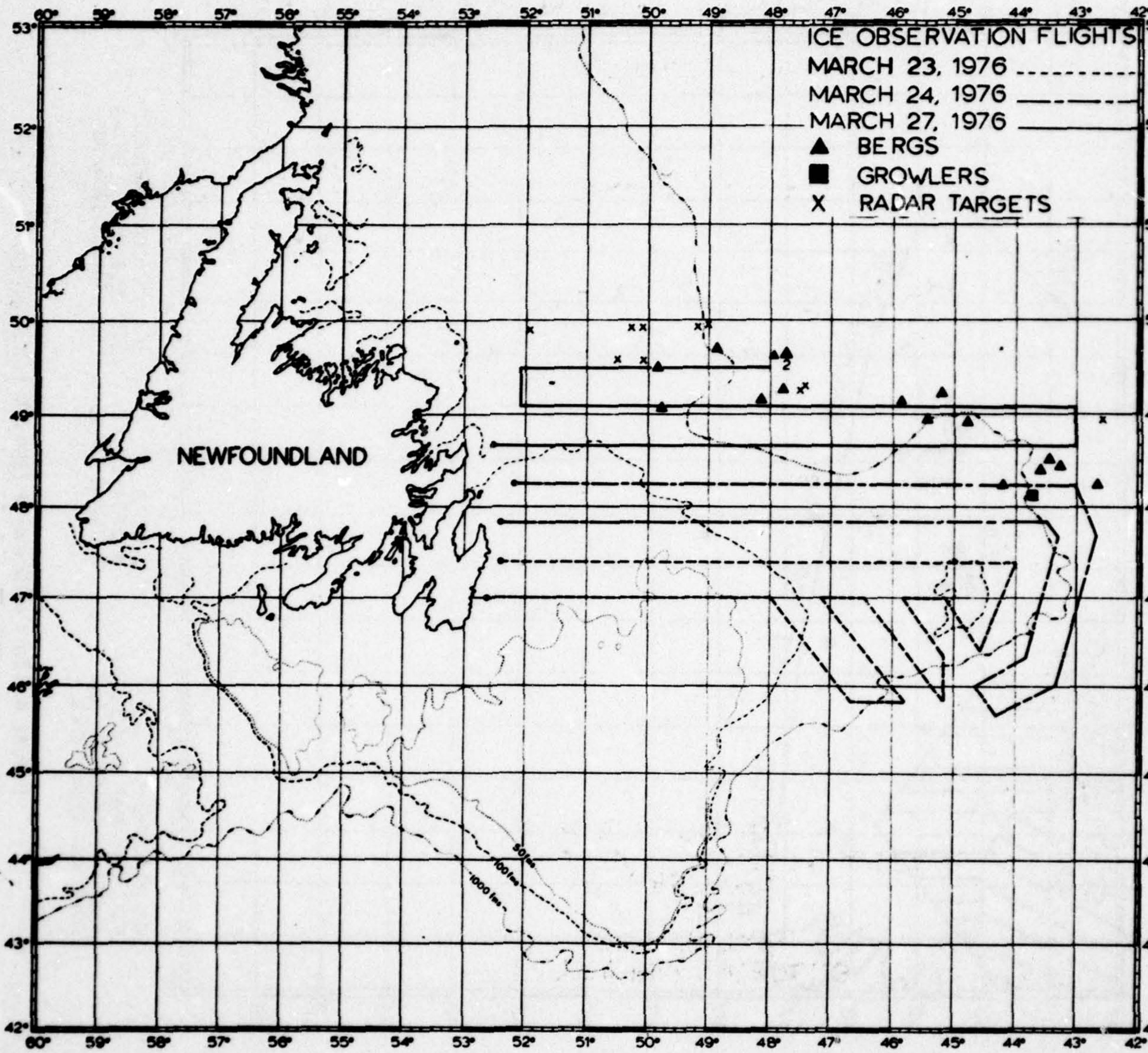


FIGURE 5.—Ice Observation Flights on 23, 24 and 27 March 1976

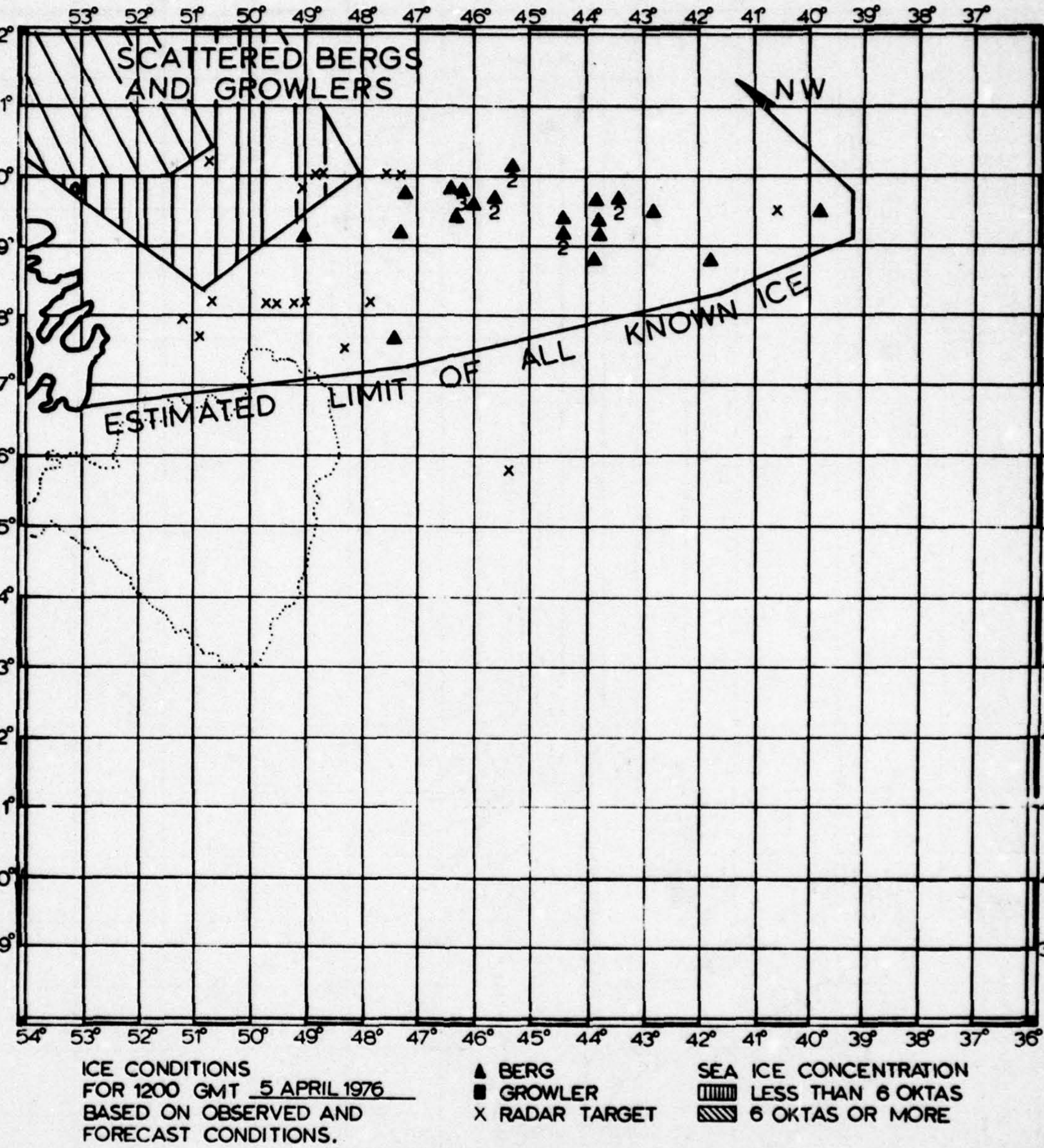


Figure 6.—Ice Conditions at 1200 GMT, 5 April 1976

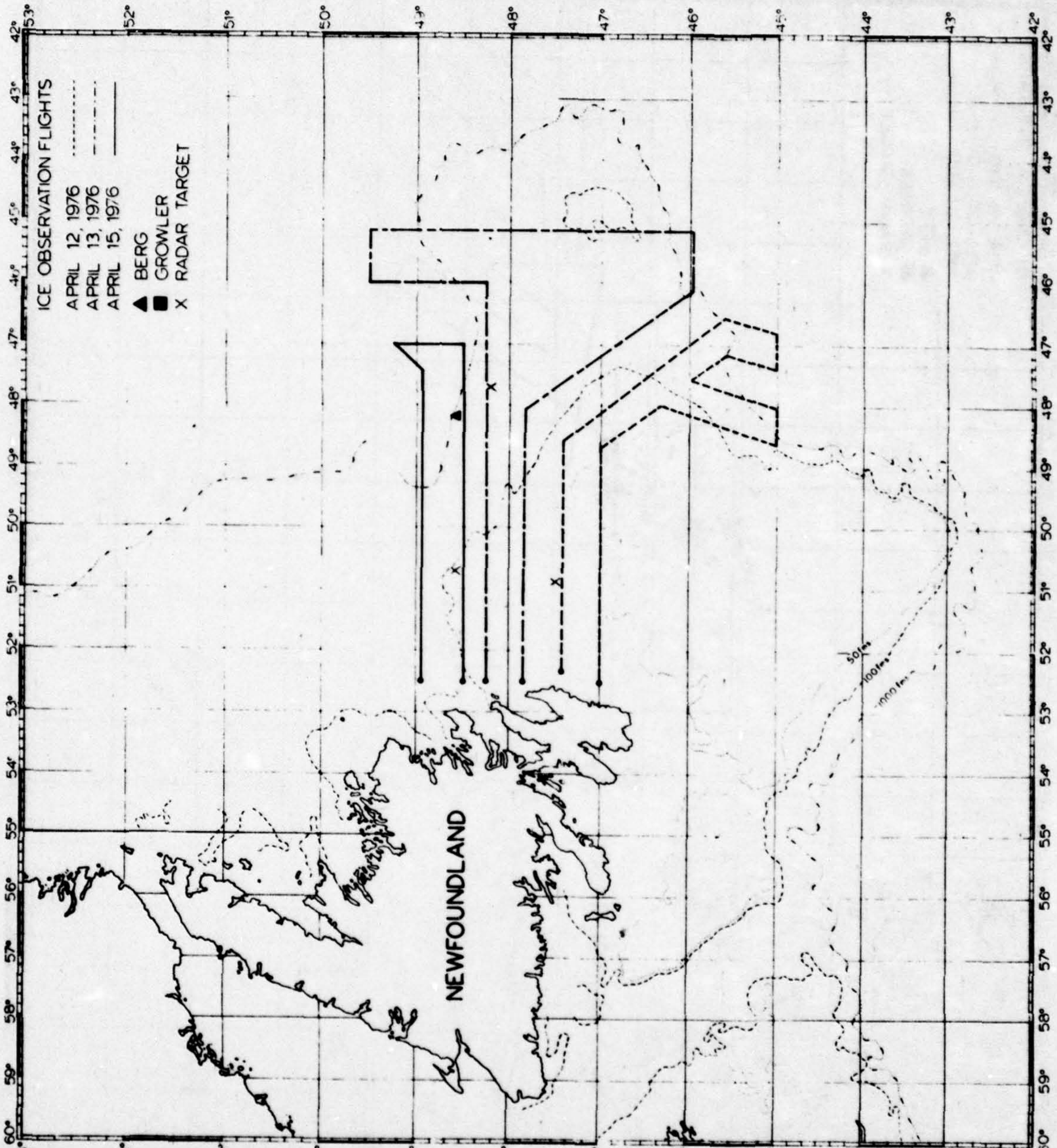


FIGURE 7.—Ice Observation Flights on 12, 13 and 15 April 1976

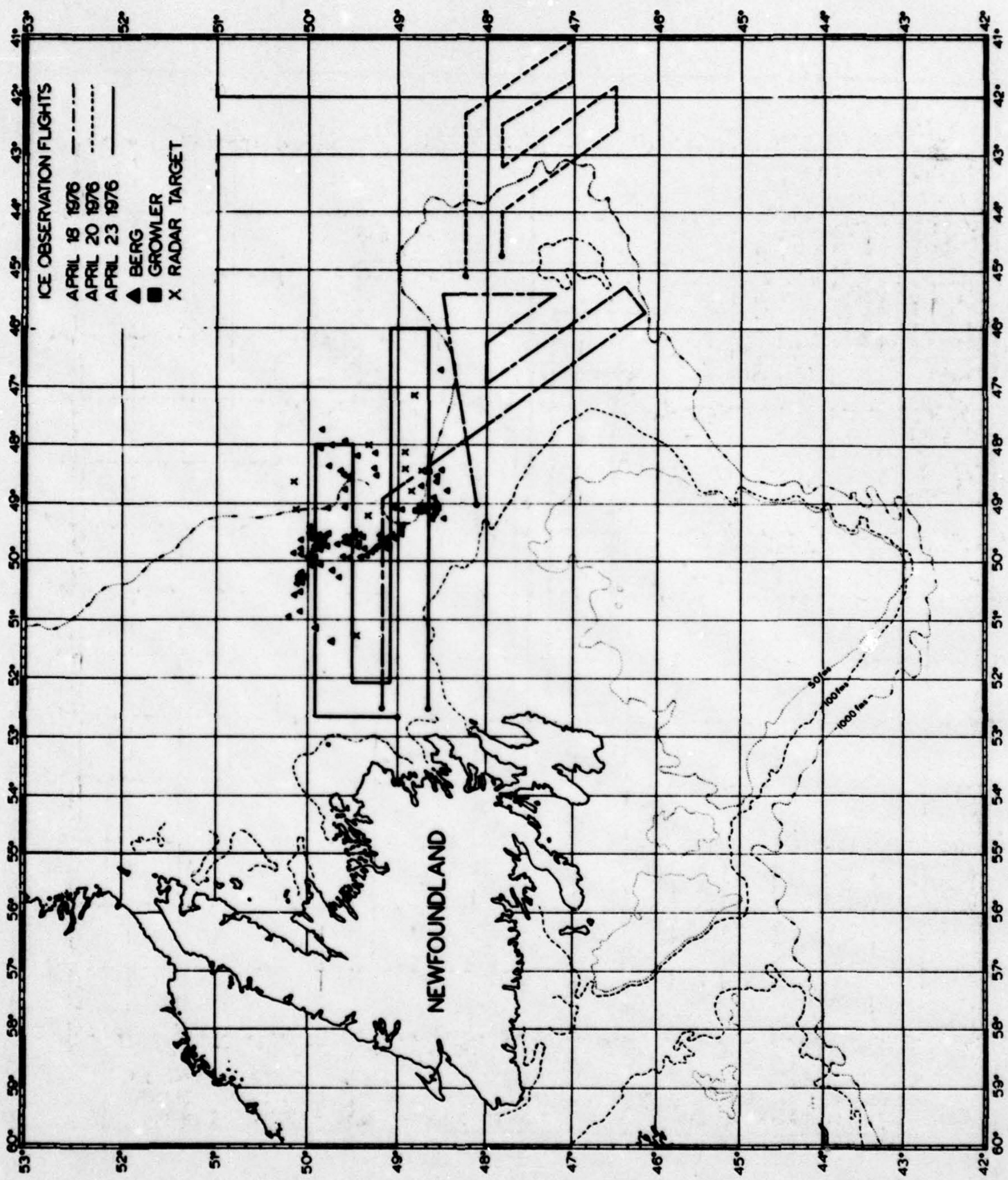


FIGURE 8.—Ice Observation Flights on 18, 20 and 23 April 1976

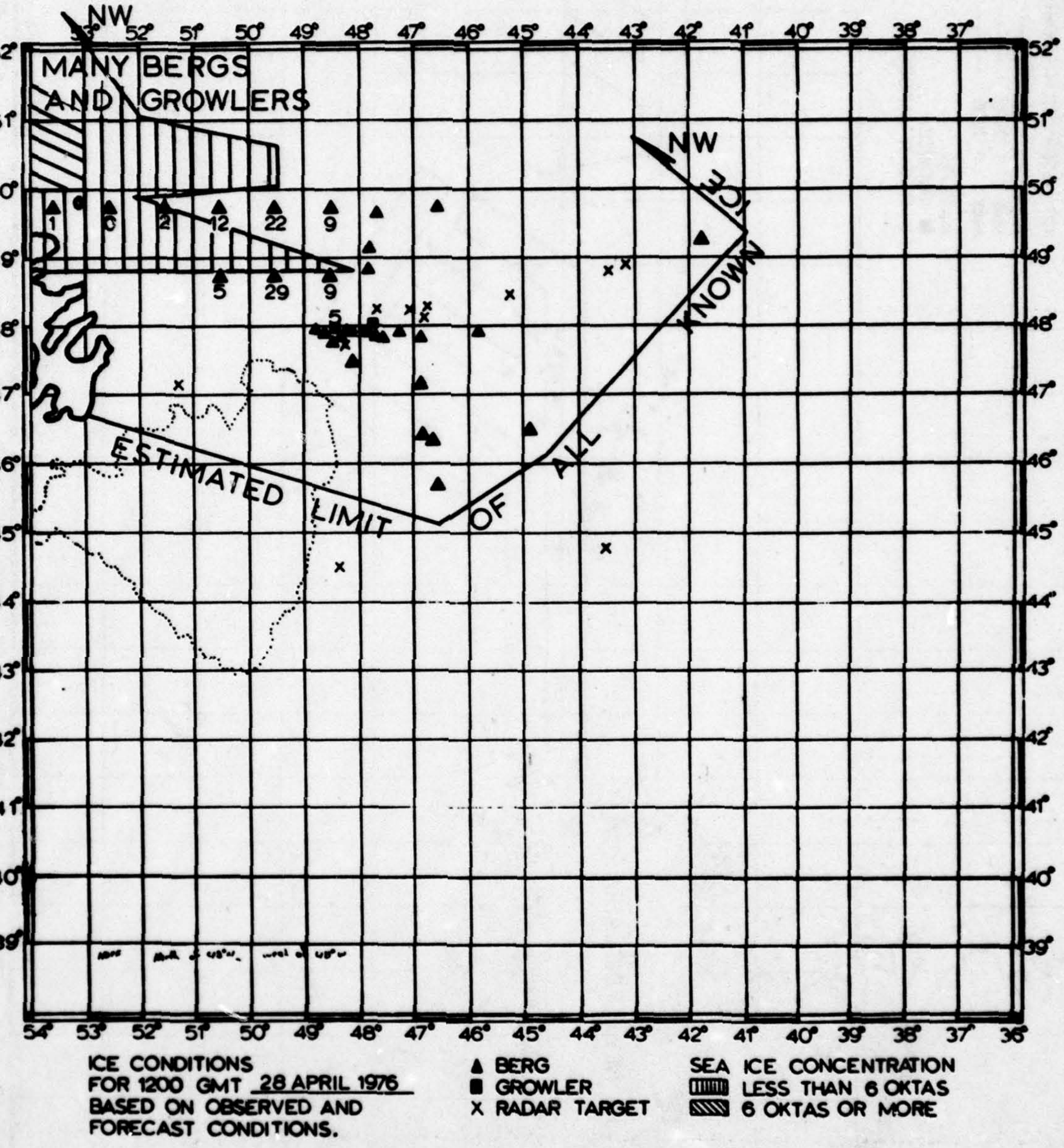


Figure 9.—Ice Conditions at 1200 GMT, 28 April 1976

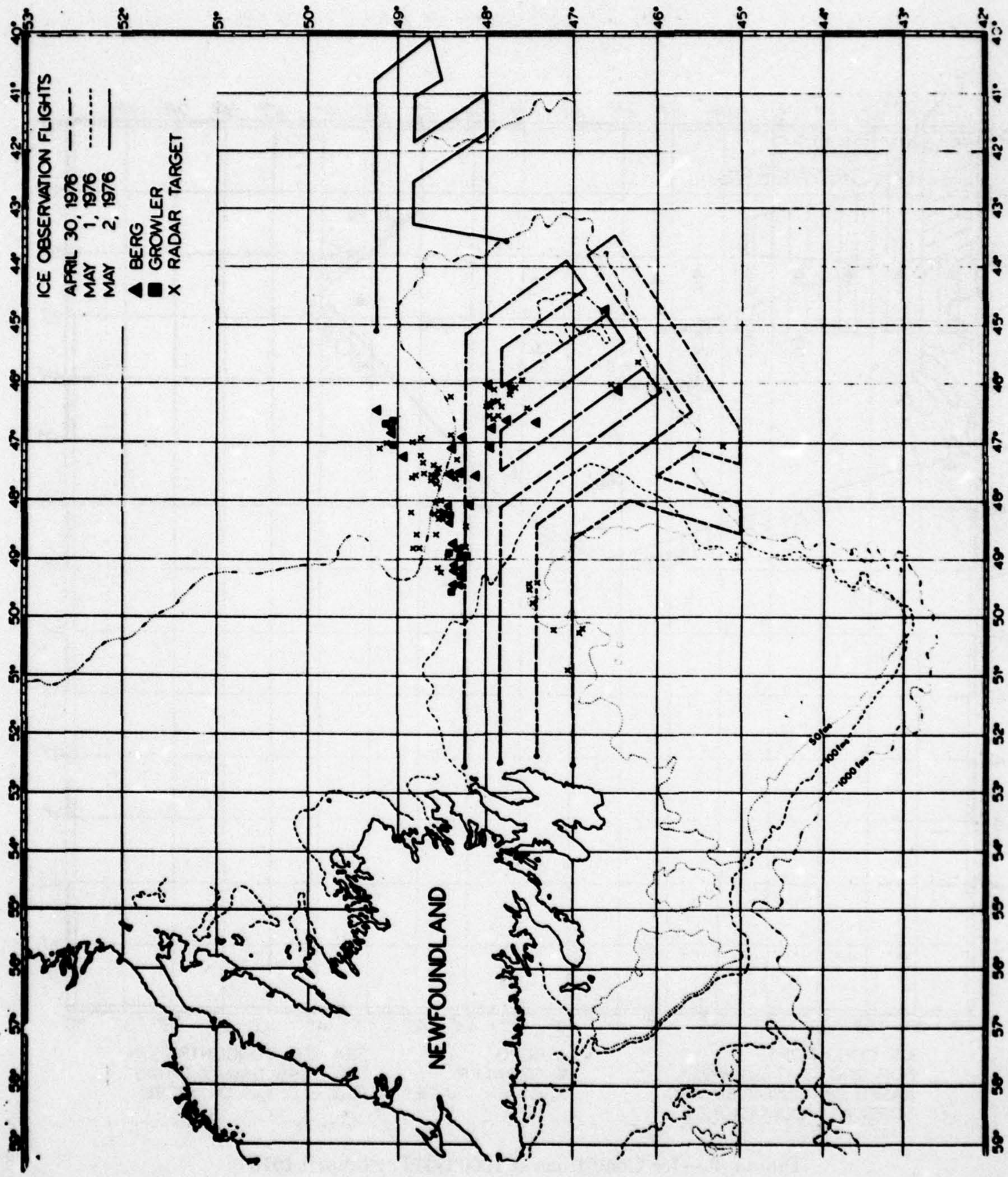


FIGURE 10.—Ice Observation Flights on 30 April and 1 and 2 May 1976

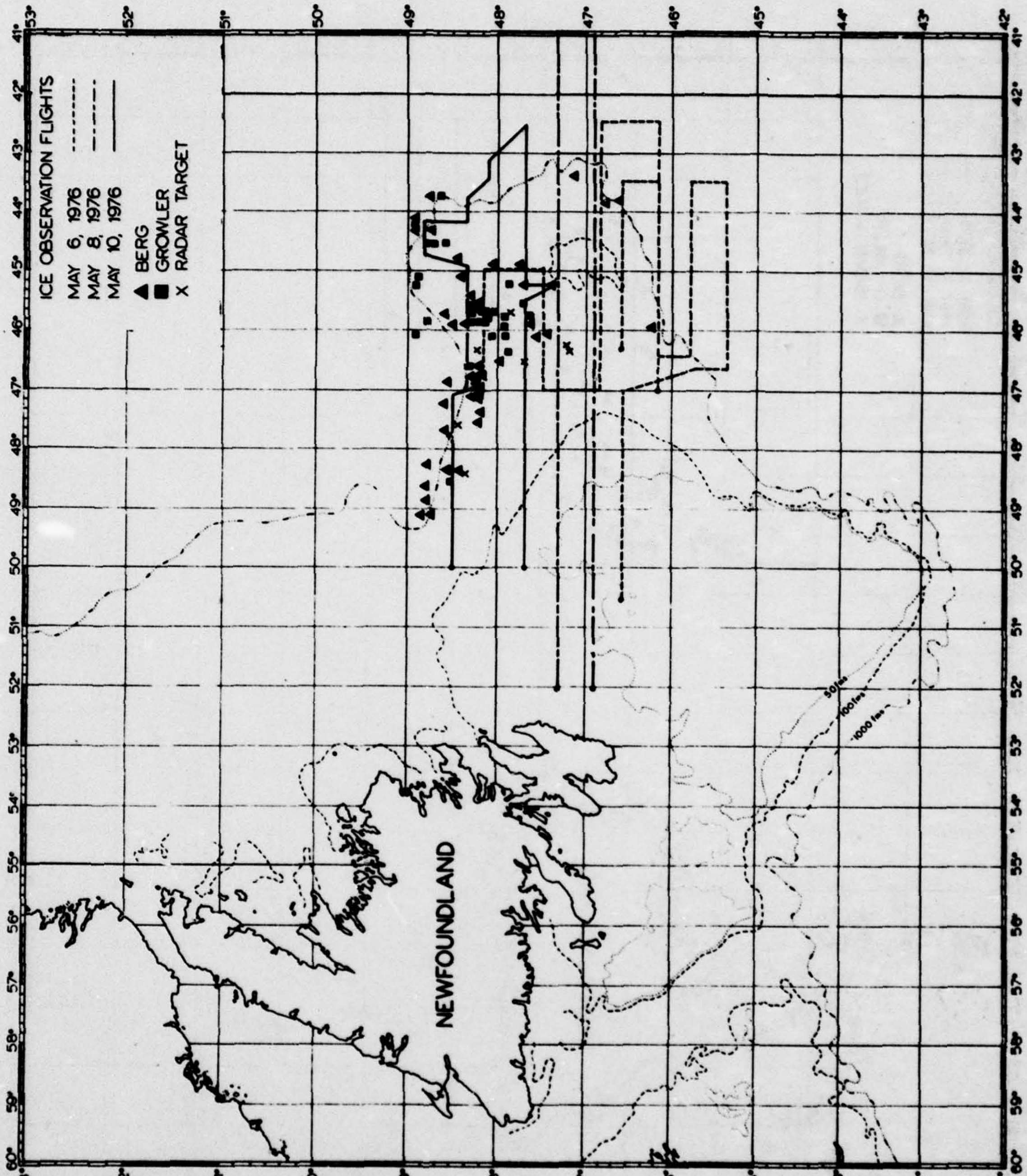


FIGURE 11.—Ice Observation Flights on 6, 8 and 10 May 1976

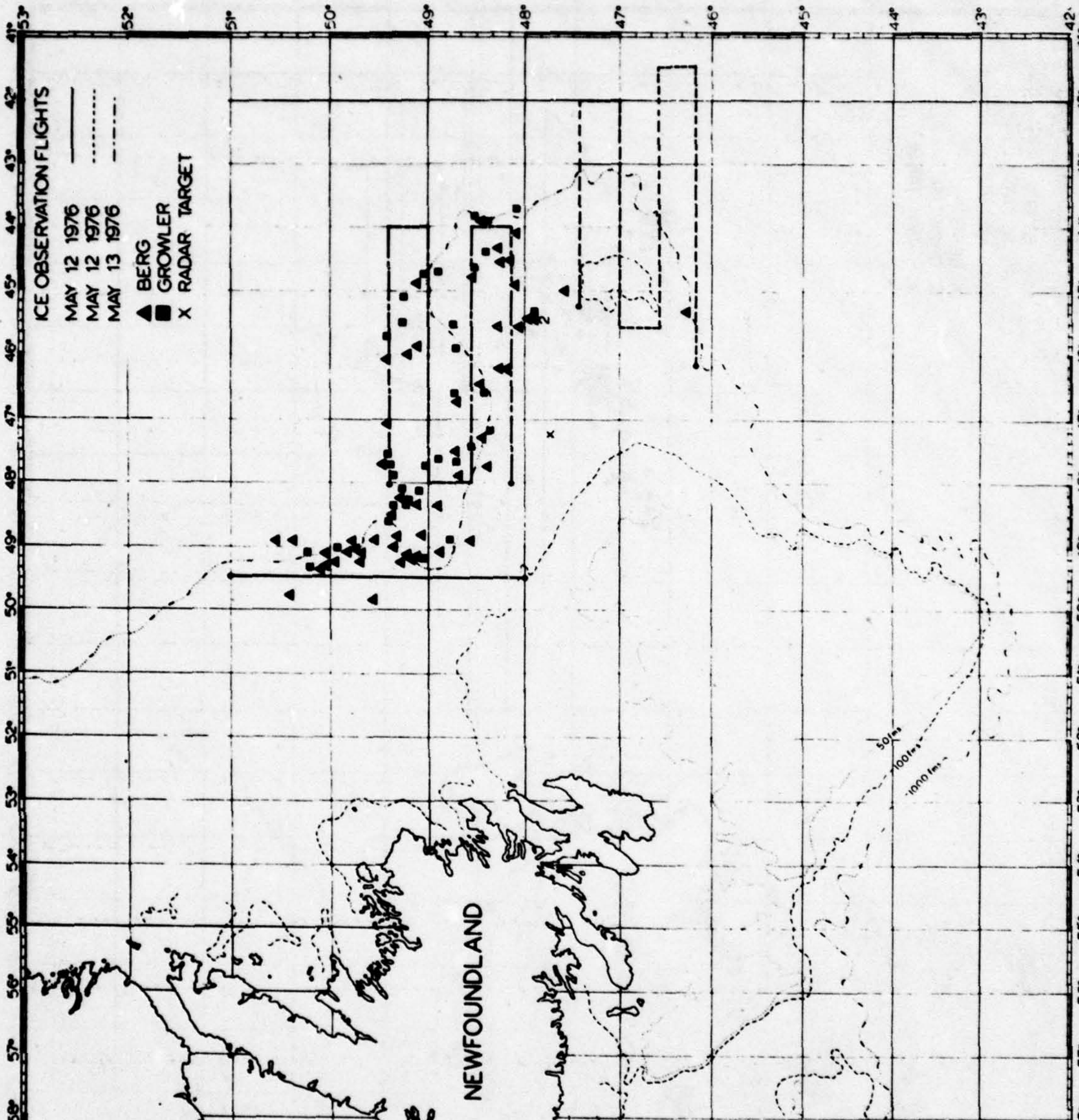


Figure 12.—Ice Observation Flights on 12 and 13 May 1976

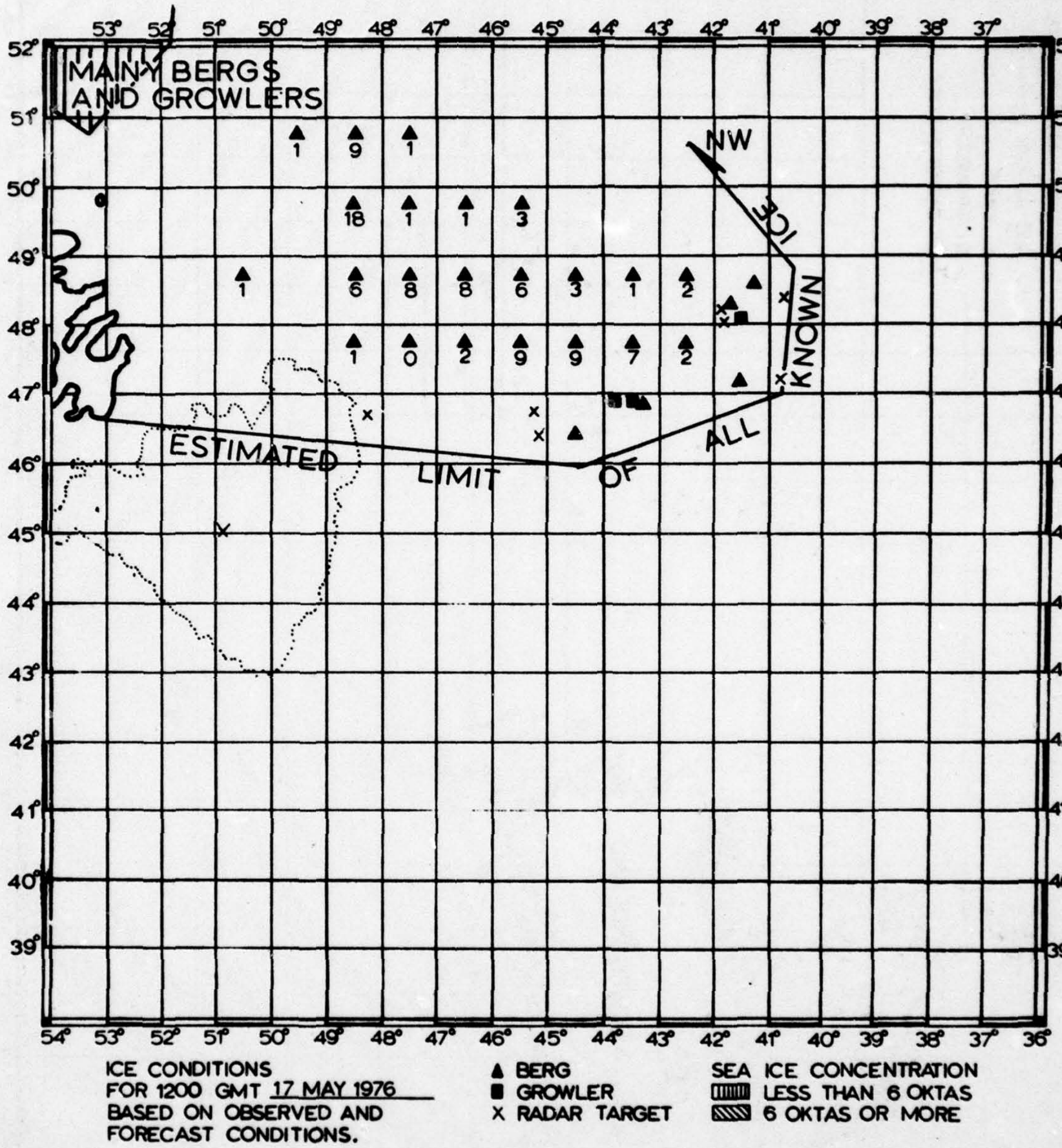


Figure 13.—Ice Conditions at 1200 GMT, 17 May 1976

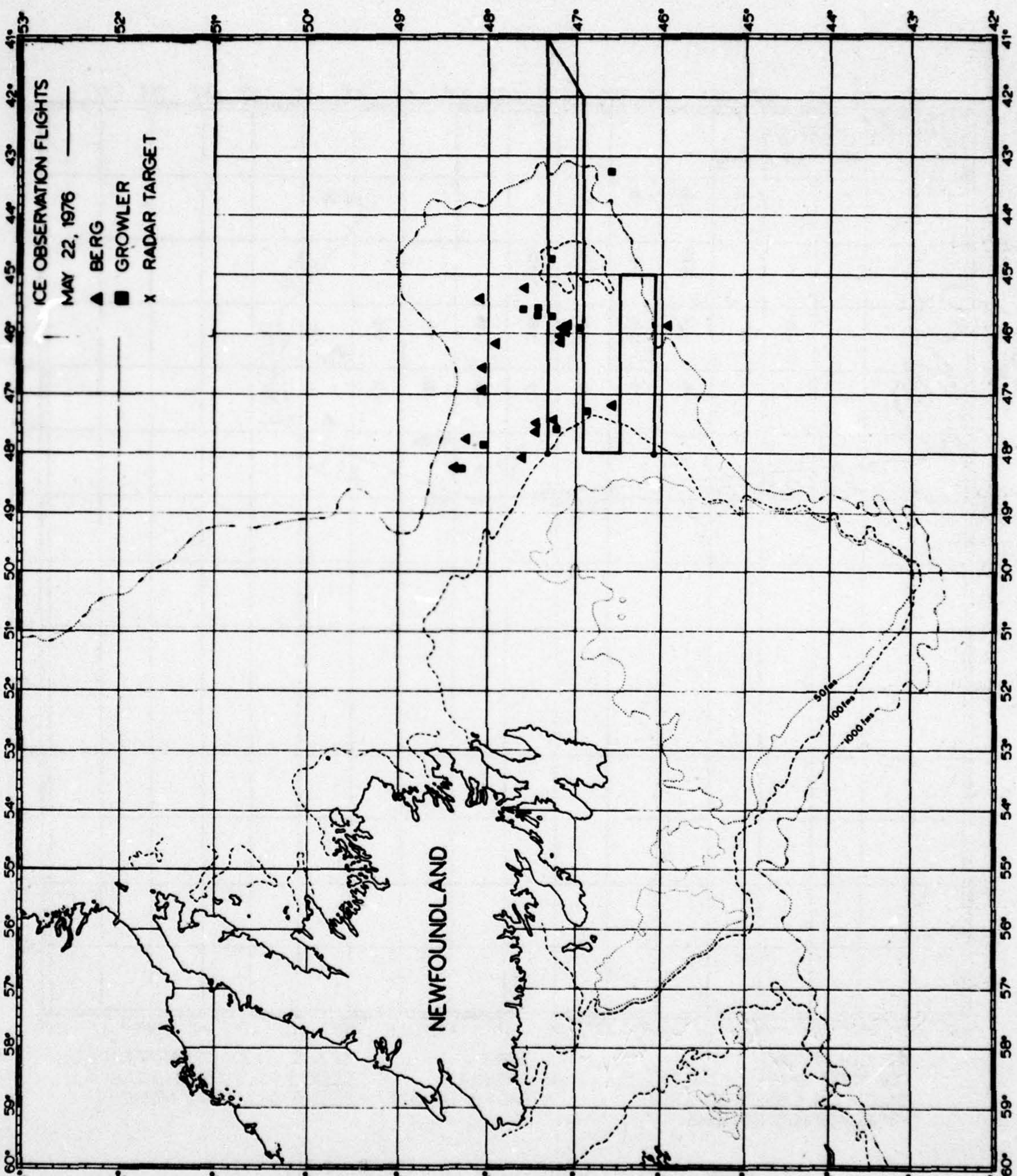


Figure 14.—Ice Observation Flight on 22 May 1976

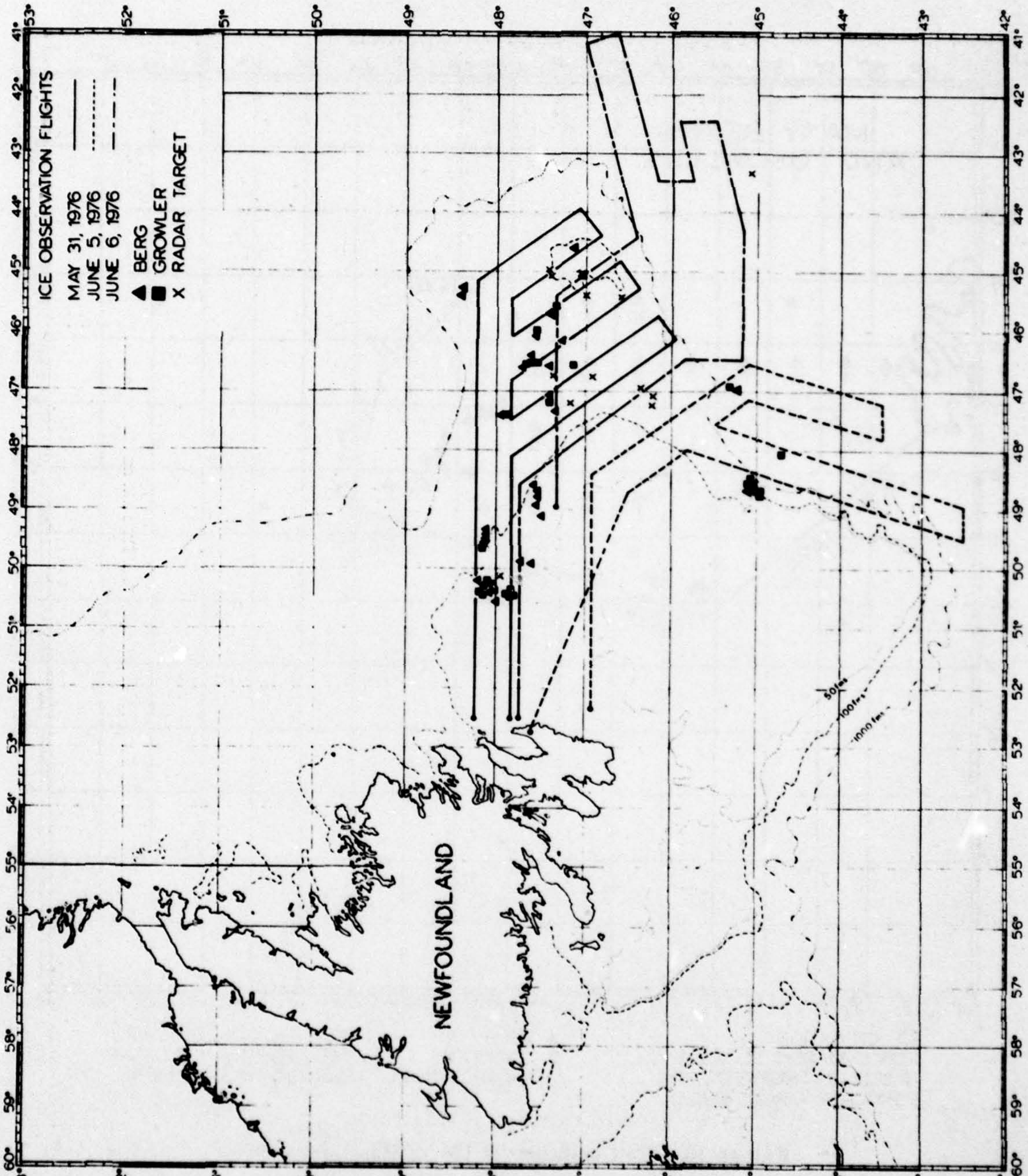


FIGURE 15—Ice Observation Flights on 31 May and 5 and 6 June 1976

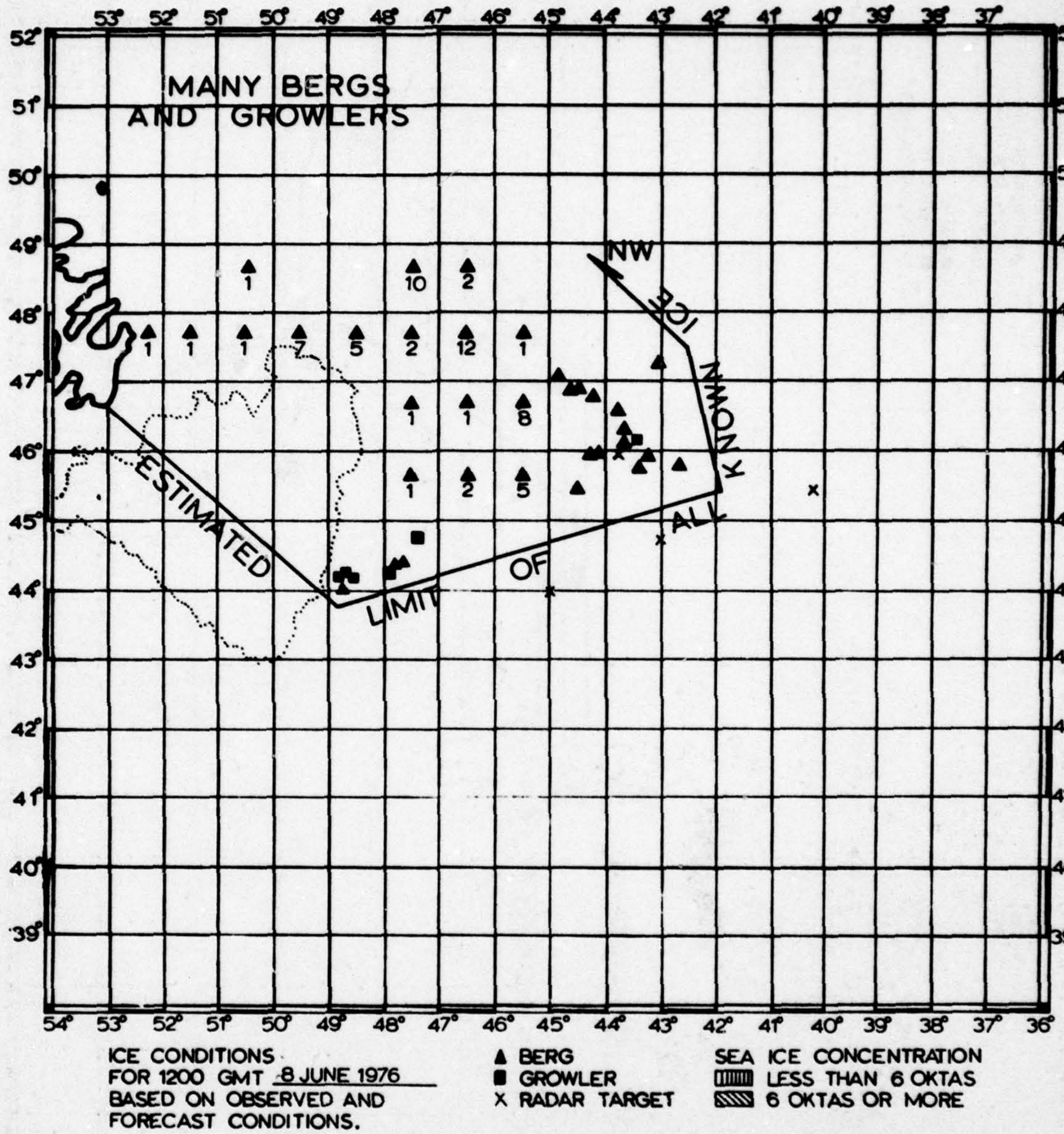


Figure 16.—Ice Conditions at 1200 GMT, 8 June 1976

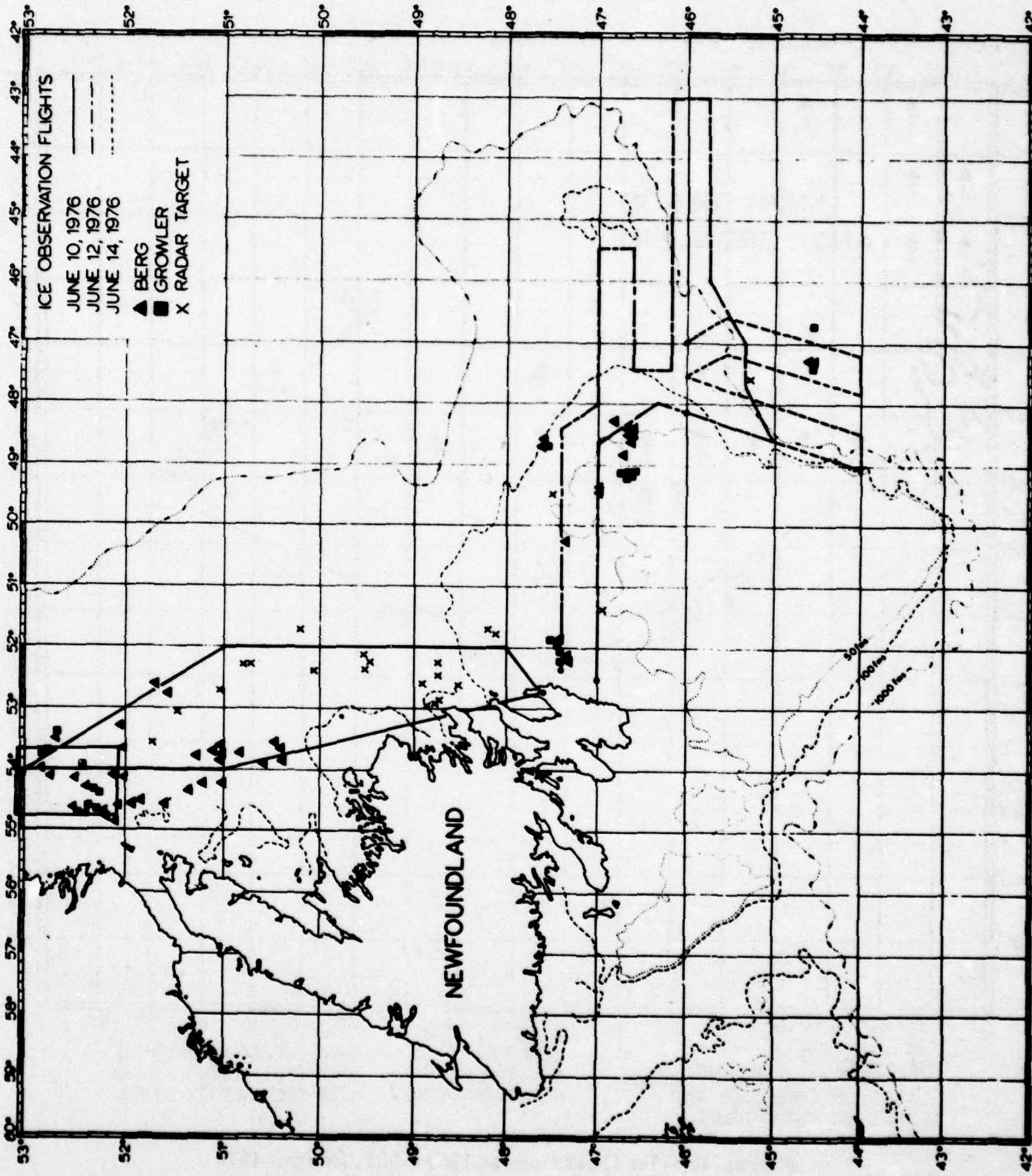


FIGURE 17.—Ice Observation Flights on 10, 12 and 14 June 1976

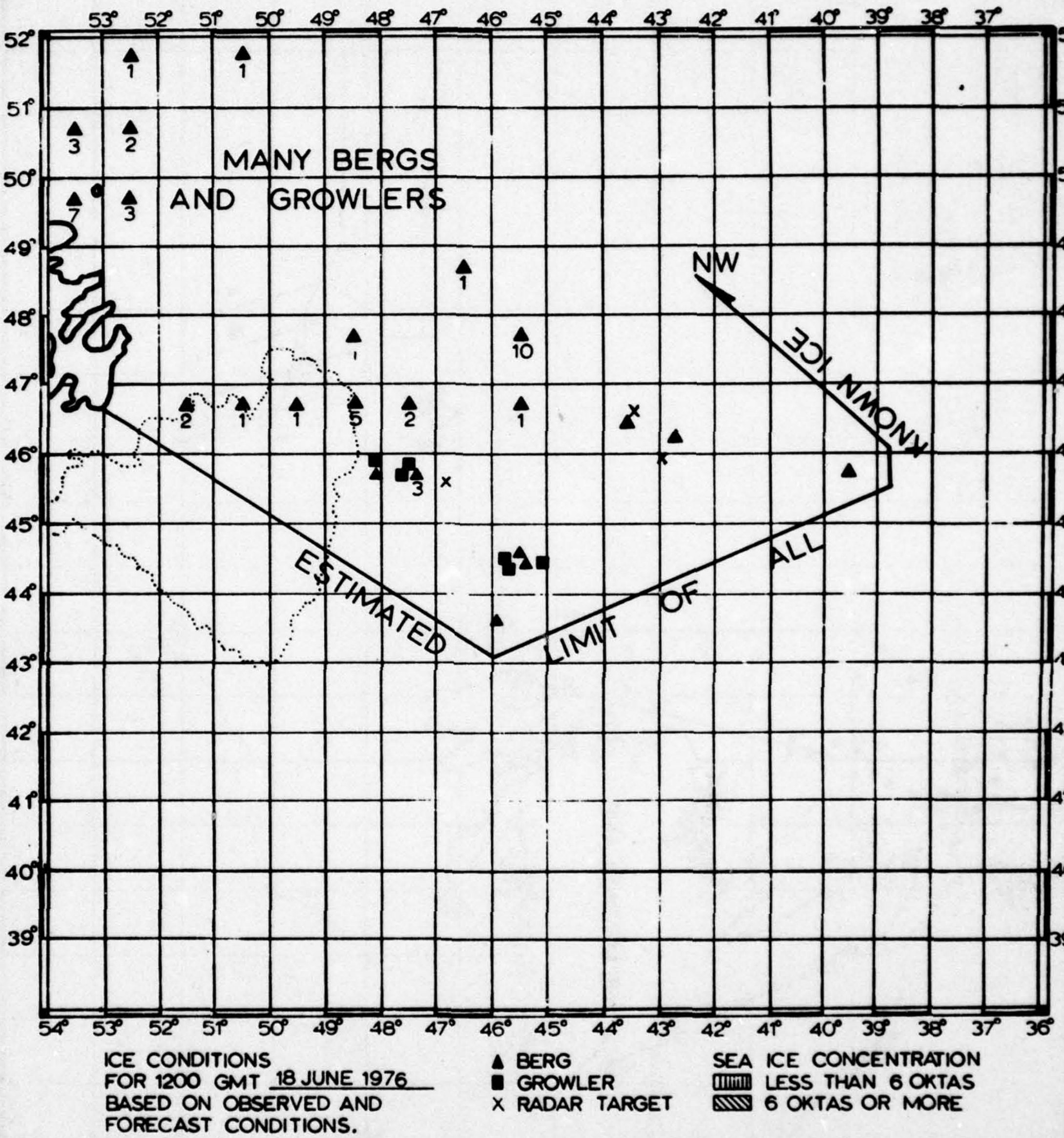


Figure 18.—Ice Conditions at 1200 GMT, 18 June 1976

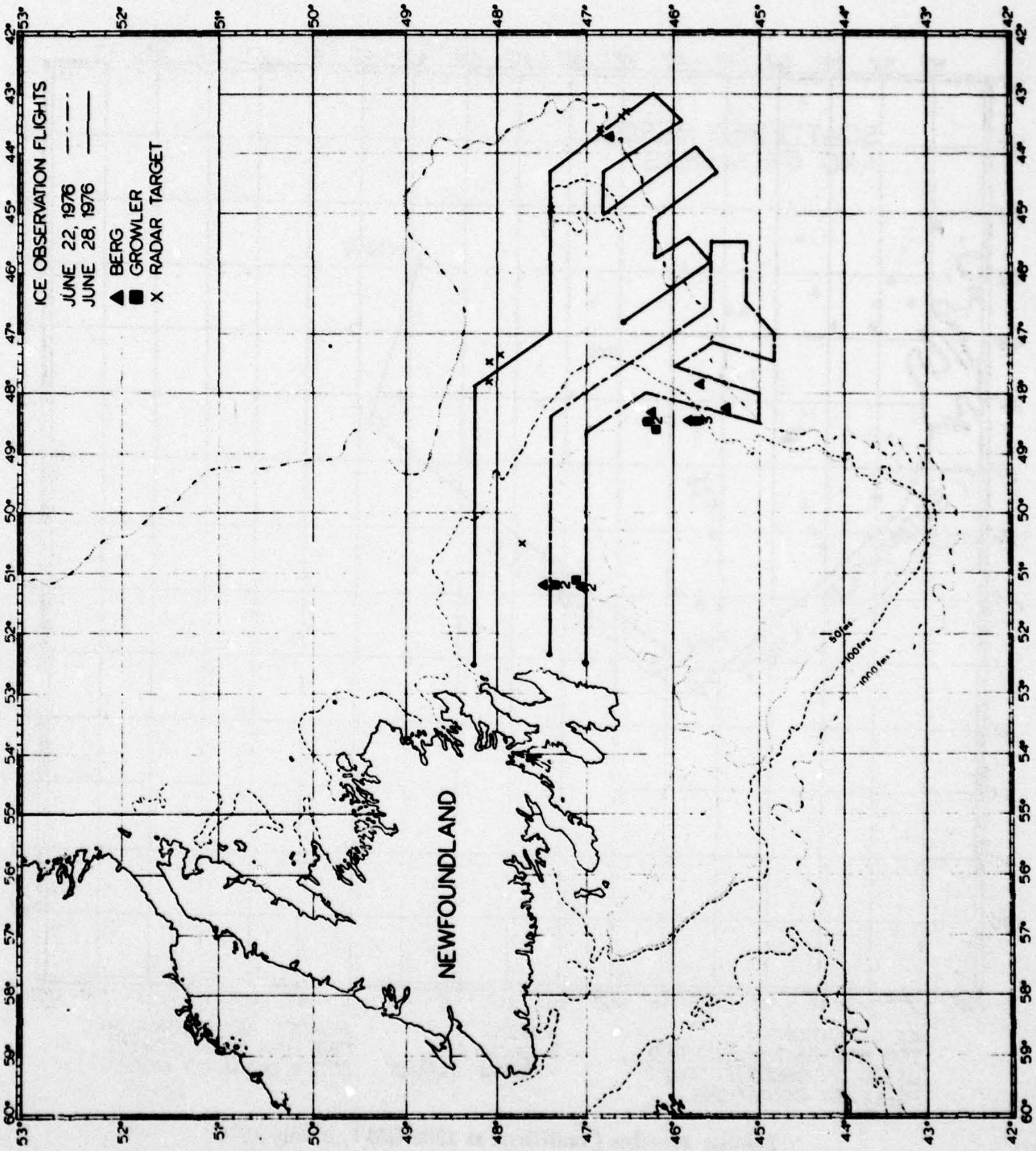


FIGURE 19.—Ice Observation Flights on 22 and 28 June 1976

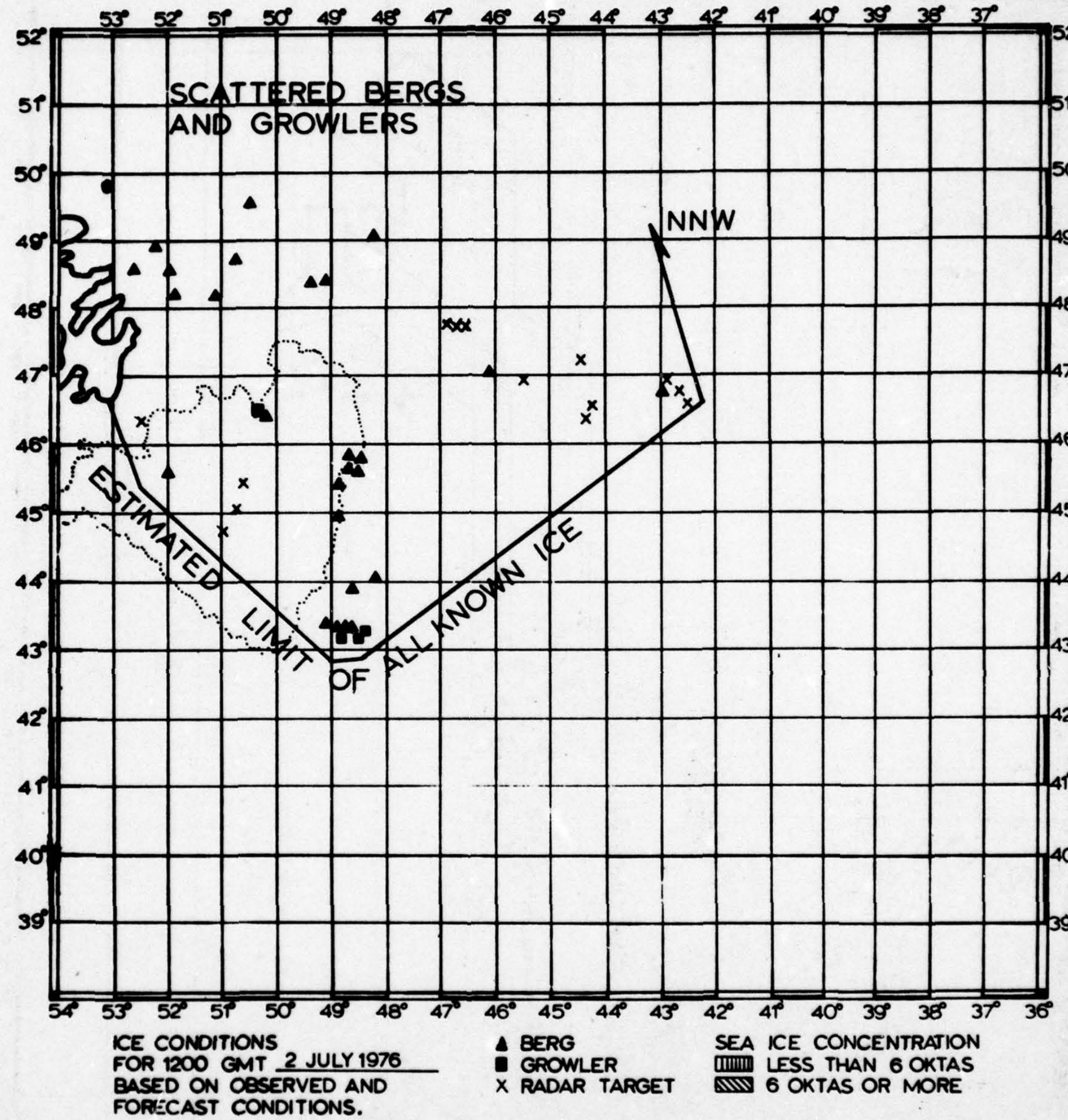


Figure 20.—Ice Conditions at 1200 GMT, 2 July 1976

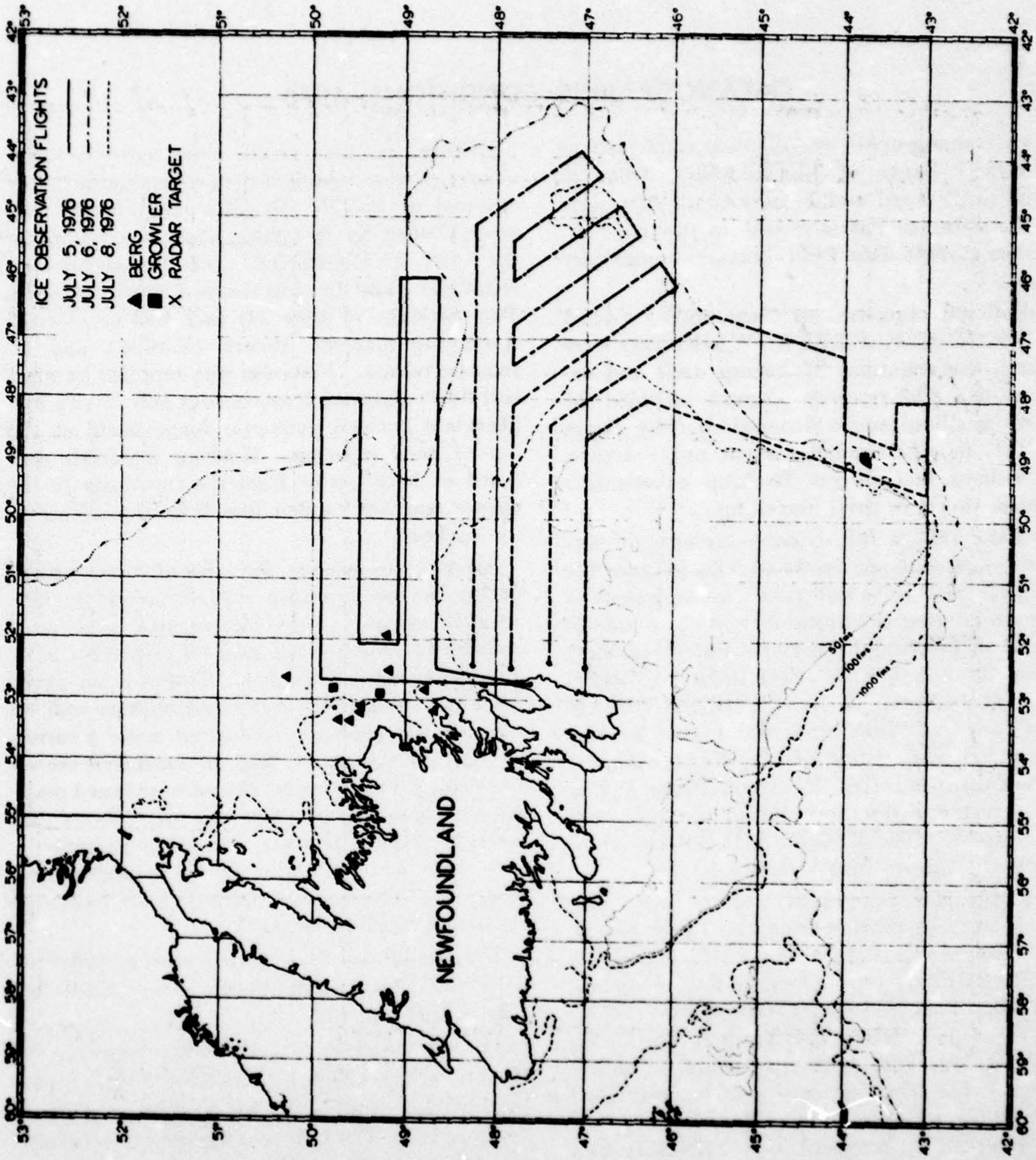


FIGURE 21.—Ice Observation Flights on 5, 6 and 8 July 1976

OCEANOGRAPHIC CONDITIONS, 1976

Two oceanographic cruises were conducted to the Grand Banks of Newfoundland from 25 March to 25 April and 18 May to 30 June during the 1976 Ice Patrol Season to provide real-time sea current data from dynamic topography surveys.

Additional objectives of these cruises aboard the USCGC EVERGREEN (WAGO 295) were research investigations of iceberg drift and deterioration. The research program included the use of satellite-tracked drogued drifting bouys (BTTs), *in situ* moored current meter arrays, and iceberg and drogue tracking experiments designed to aid in drift modelling.

In June 1976, a full dynamic topography survey encompassing section A4 to A1B (Figure 22) was performed in conjunction with an extensive survey conducted simultaneously in the waters to the east of the Grand Banks Ice Patrol standard sections by the USCGC SHERMAN (WHEC 720). The purpose of the USCGC SHERMAN cruise was to better understand the detailed dynamic characteristics of the North Atlantic Current after it leaves the Grand Banks and to determine the water properties of the associated water masses. The USCGC SHERMAN cruise data is the subject of a separate report.

The dynamic topography surveys were conducted by field parties from the Coast Guard Oceanographic Unit and the crew of the USCGC EVERGREEN using the Plessey Environmental System, Inc. Salinity/Temperature/Depth (S/T/D) or Conductivity/Temperature/Depth (C/T/D) Model 9040, Environmental Profiling Systems. The measurements were made to 1000 decibars (or to near bottom if shallower) and were recorded on magnetic tape (Kennedy Co., Model 1600R tape recorder) after formatting by a digital data logger (Sonicraft, Inc. DDL). For data processing details see Mountain (1978). The method of calculating dynamic height in water depth less than the reference level (1000 decibars for the Ice Patrol) is described in Kollmeyer (1967).

During the first cruise three current meter moorings were established in a triangular array centered at 42–47N, 47–47W. Deployment was accomplished by launching from the fantail of the CGC EVERGREEN with the anchor last technique while the ship steamed slowly forward. The moorings (Figure 23) each had two Vector Averaging Current Meters (VACM) and an acoustic release. Flotation was supplied by glass ball floats above each instrument and by two 31" fiberglass covered syntactic foam floats at the top of each mooring. Mooring materials consisted of 3/16" wire from the top floats to the release and 5/8" nylon line from the release to the anchor.

Attempts to recover the current meter arrays during the second cruise were unsuccessful. The acoustic releases were interrogated and commanded to release. All releases responded as if disengagement had occurred. However, no signal from the submersible radio transmitters and no sighting was made of the current meter mooring on the surface even after an extensive search was made. The acoustic releases were heard pinging continuously in place for the life of the battery (about 5 hours). Dragging attempts in both 1976 and 1977 also failed to recover the moorings. The cause of failure of the moorings to surface remains unknown.

The results of the iceberg tracking study for drift and deterioration appears in a separate section in this bulletin.

The contoured field of dynamic topography on the first cruise (Figure 24 and 25) reveals a pattern of flow similar to the average conditions (Figure 26). The Labrador Current flows southward through Flemish Pass following the eastern edge of the Grand Banks. Surveys from the second cruise (Figure 27) provide a full coverage of the area bounded by the standard Ice Patrol sections. The dynamic height field at this time exhibits good agreement with the normal topography in the northern sections of the survey,

but the location and density of the dynamic height isopleths indicates that the North Atlantic Current as it passes across section A4 to 40-60 nautical miles north of its average position.

The full dynamic topography survey provided an opportunity to study the variation of the transport and minimum temperature in the Labrador Current as it flowed southward. Both the total southerly transport and the Cold Core transport (less than 2°C and 34.3°/₀₀) have been calculated (Figure 28). Only about half of the Labrador Current at section A1B turned southward to follow the eastern slope of the Grand Banks. This southward flow remained relatively constant between sections A2 and A3B at about 2.5 Sv. The transport values computed for these sections are comparable in volume to the Labrador Current transports measured in recent years, but was below the long-term average of about 3.5 Sv (Bullard, *et al.*, 1961). At sections A3B MOD and A3C the transport inexplicably increased. When the flow had reached section A4, the volume transport had decreased almost to zero because of the unusually northerly location of the North Atlantic Current. This had a damming effect on the Labrador Current preventing its usual turn to the west around the Tail of the Bank. The minimum temperatures measured in the Labrador Current were nearly the same with the northernmost section showing the coldest water and the southernmost section having the warmest water as expected. Average minimum temperature was about 1.2°C (Bullard, *et al.*, 1961).

Although the effect on the Labrador Current of the impingement by the North Atlantic Current on the Tail of the Bank can easily be seen in the contoured dynamic height field (Figure 27), a temperature-salinity (T-S) graphical analysis was made to confirm and explore the presence of the blockade (Figures 29a and 29b). From the T-S curves it is evident that very little volume with Labrador water properties reaches section A4. The small volume of Labrador water present on section A4 (all of which is below approximately 25 meters in the three northernmost stations) represents a volume transport only 4% of that found on the next section, A3C. Furthermore, whereas the minimum temperatures of the upstream section, A3C, are −0.41°C, −1.2°, and −1.4°C for stations 12112 to 12114, the minimum temperatures for the comparable stations 12089-12091 on section A4 are +1.2°C, 0.0°C, and −1.0°C. The salinity is quite similar for all six stations at about 33.0°/₀₀ to 33.2°/₀₀. On A3C water with Labrador properties is seen out to station 12106.

Since the continental slope rises sharply to the west, little of the volume transport from the blocked Labrador Current can be transported onto the shelf. Consequently, most of the volume flow must be turned eastward to flow along with the North Atlantic Current. This northward migration of the North Atlantic Current on section A4 is very similar to the conditions observed during the 1973 Ice Patrol Season (Hayes and Robe, 1978).

REFERENCES

Bullard, R. P., R. P. Dinsmore, A. P. Franceschetti, P. A. Morrill, and F. M. soule. 1961. Report of the International Ice Patrol in the North Atlantic Ocean, Season of 1960, U.S. Coast Guard Bulletin CG-188-15:62.

Hayes, R. M. and R. Q. Robe. 1978. Oceanography of the Grand Banks Region of Newfoundland, in 1978, U.S. Coast Guard Oceanographic Report No. 78, CG 373-78.

Kollmeyer, R. C., D. A. McGill, N. Corwin. 1967. Oceanography of the Labrador Sea in the vicinity of Hudson Strait in 1965, U.S. Coast Guard Oceanographic Unit Report No. 12, CG 373-12:3.

Mountain, D. C. 1978. Oceanography of the Grand Banks Region of Newfoundland in 1975, U.S. Coast Guard Oceanographic Report No. 75, CG 373-75.

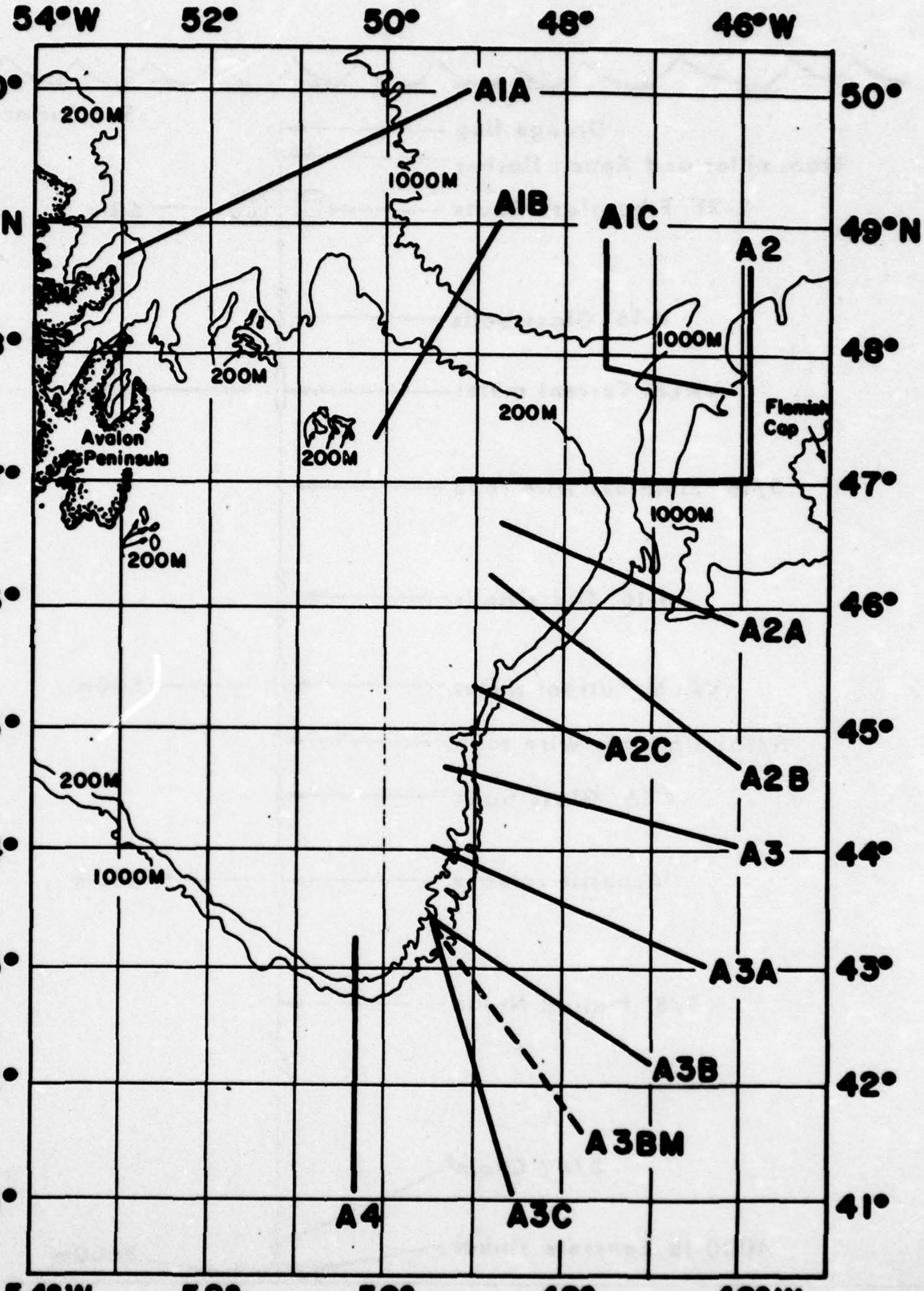


FIGURE 22.—Standard International Ice Patrol Sections

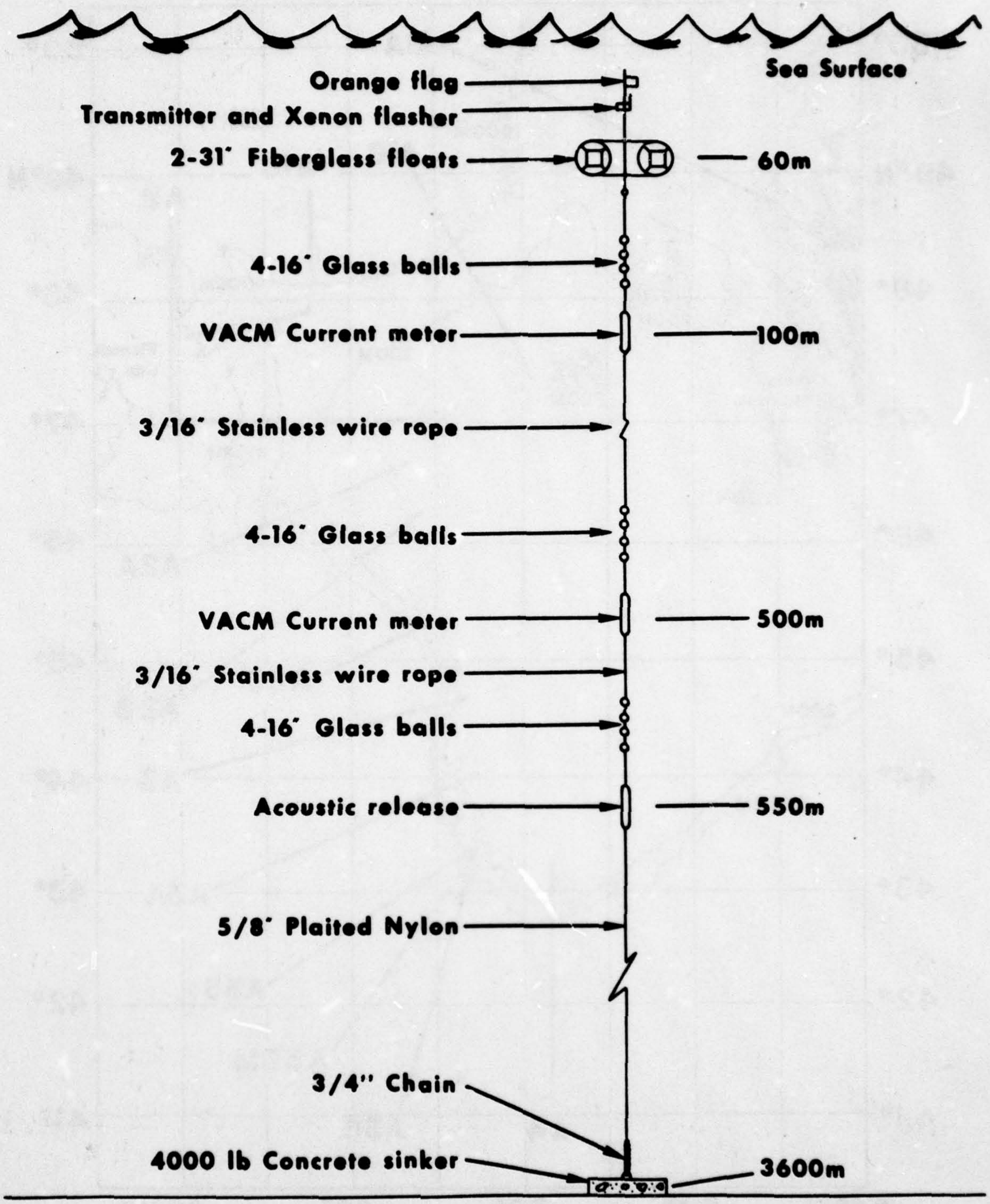


FIGURE 23.—Schematic diagram of the current meter moorings displayed in 1976

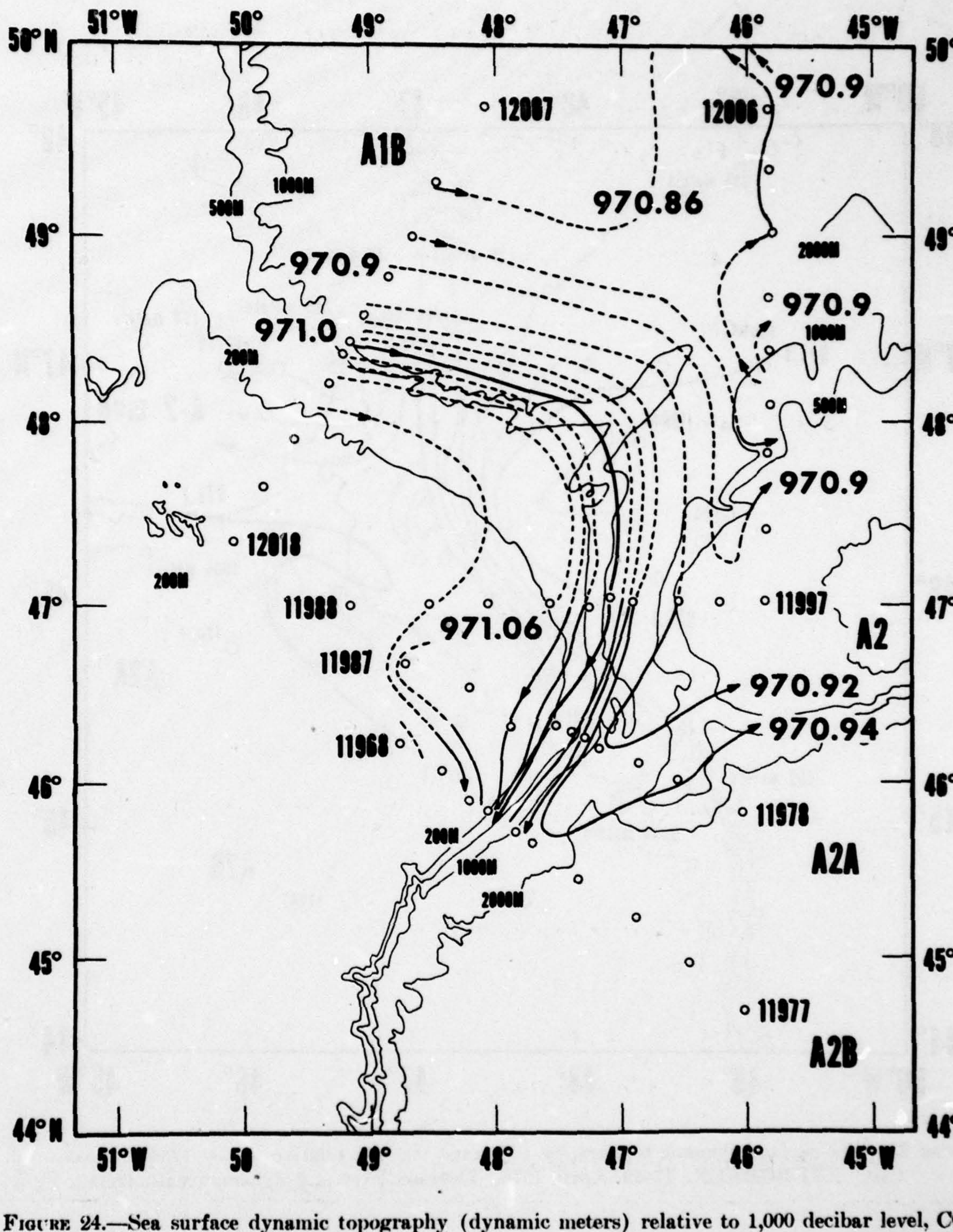


FIGURE 24.—Sea surface dynamic topography (dynamic meters) relative to 1,000 decibar level, CGC EVERGREEN, 1–6 April 1976. Contour level is 2 dynamic centimeters. Station numbers indicate turning points.

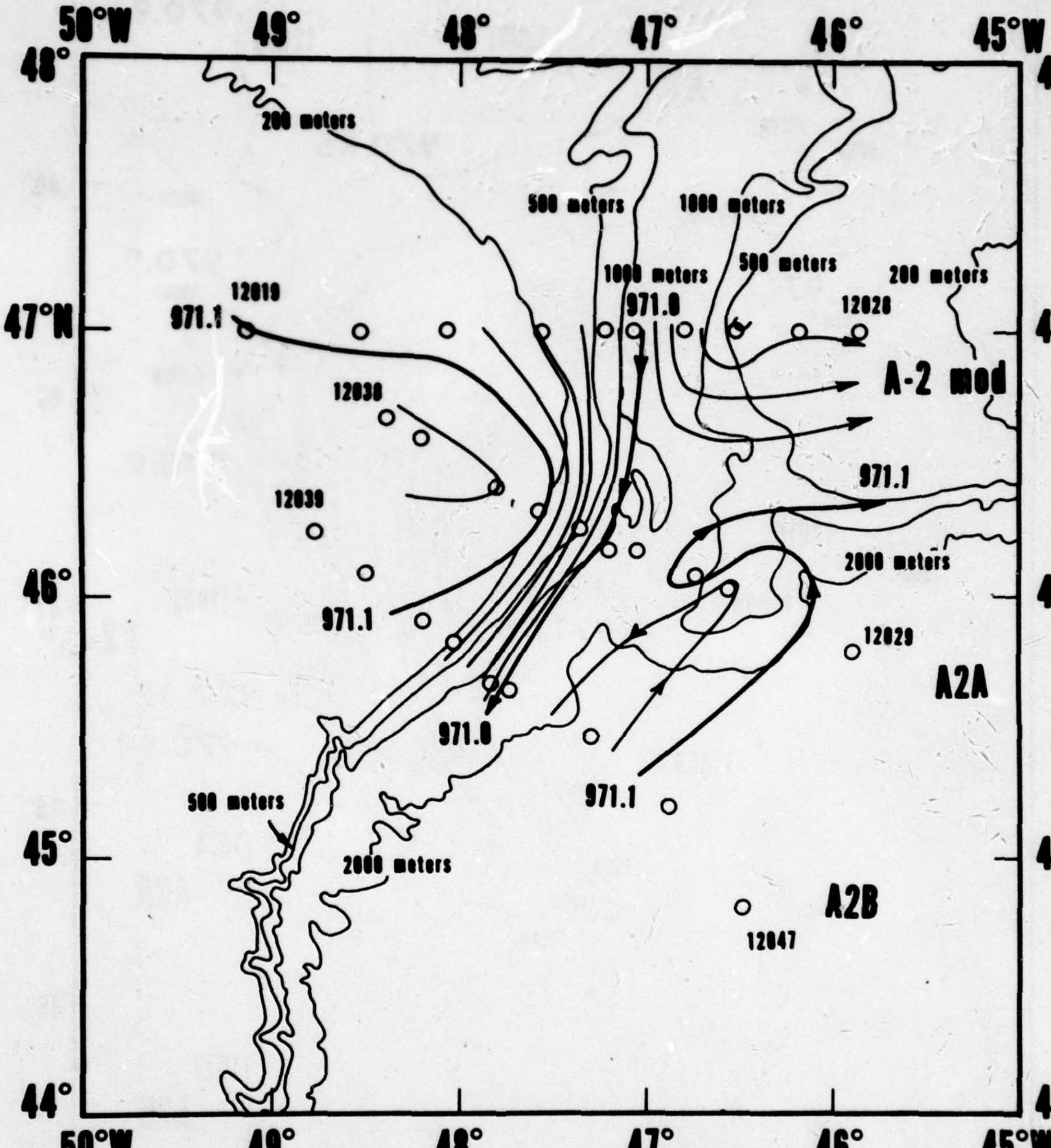


FIGURE 25.—Sea surface dynamic topography (dynamic meters) relative to the 1,000 decibar level. CGC EVERGREEN, 17–19 April 1976. Contour level is 2 dynamic centimeters

MONTHLY NORMAL DYNAMIC TOPOGRAPHY FOR APRIL

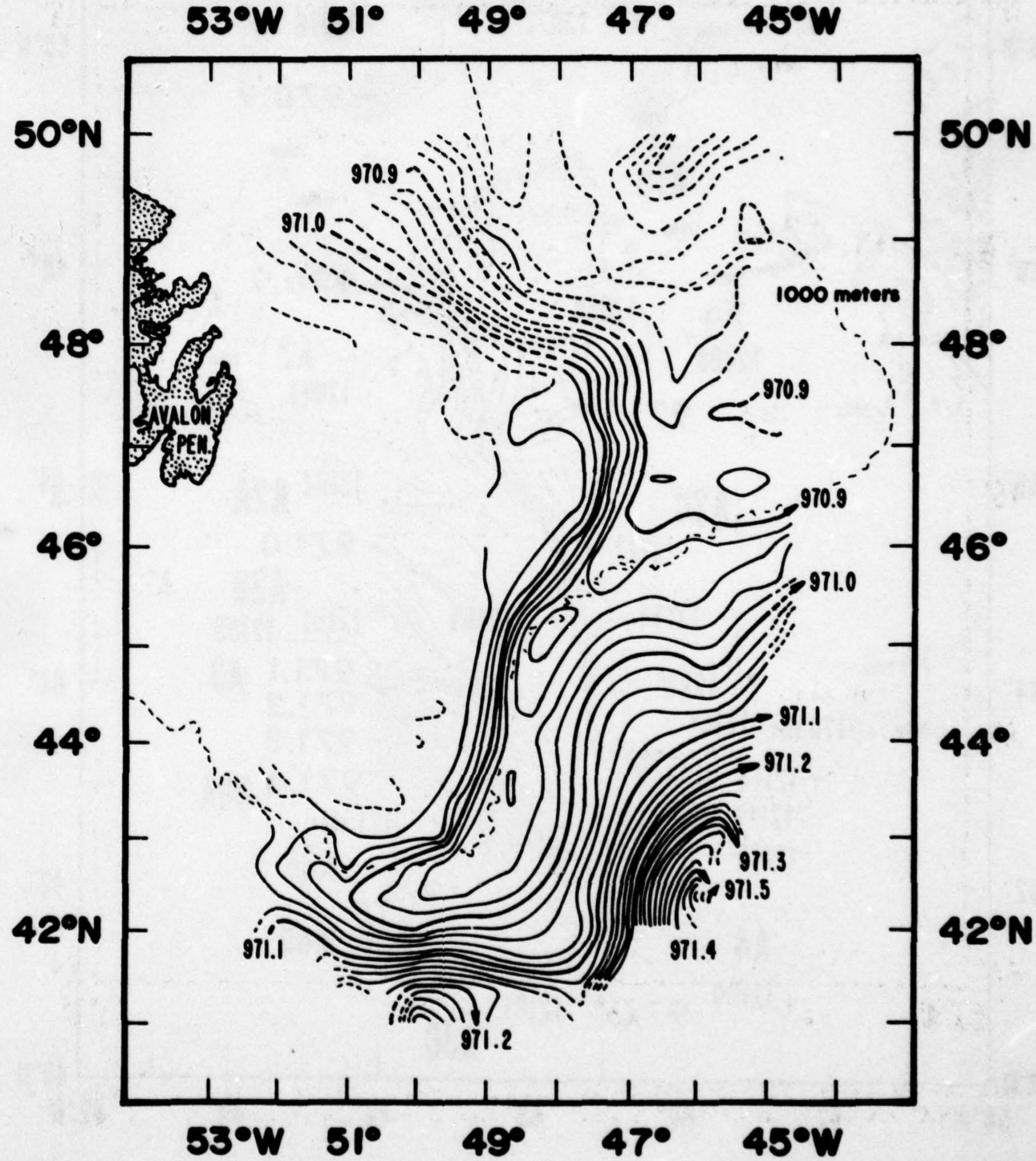


FIGURE 26.—April monthly normal dynamic topography (dynamic meters) of the sea surface relative to the 1,000 decibar surface. Contour interval is 2 dynamic centimeters

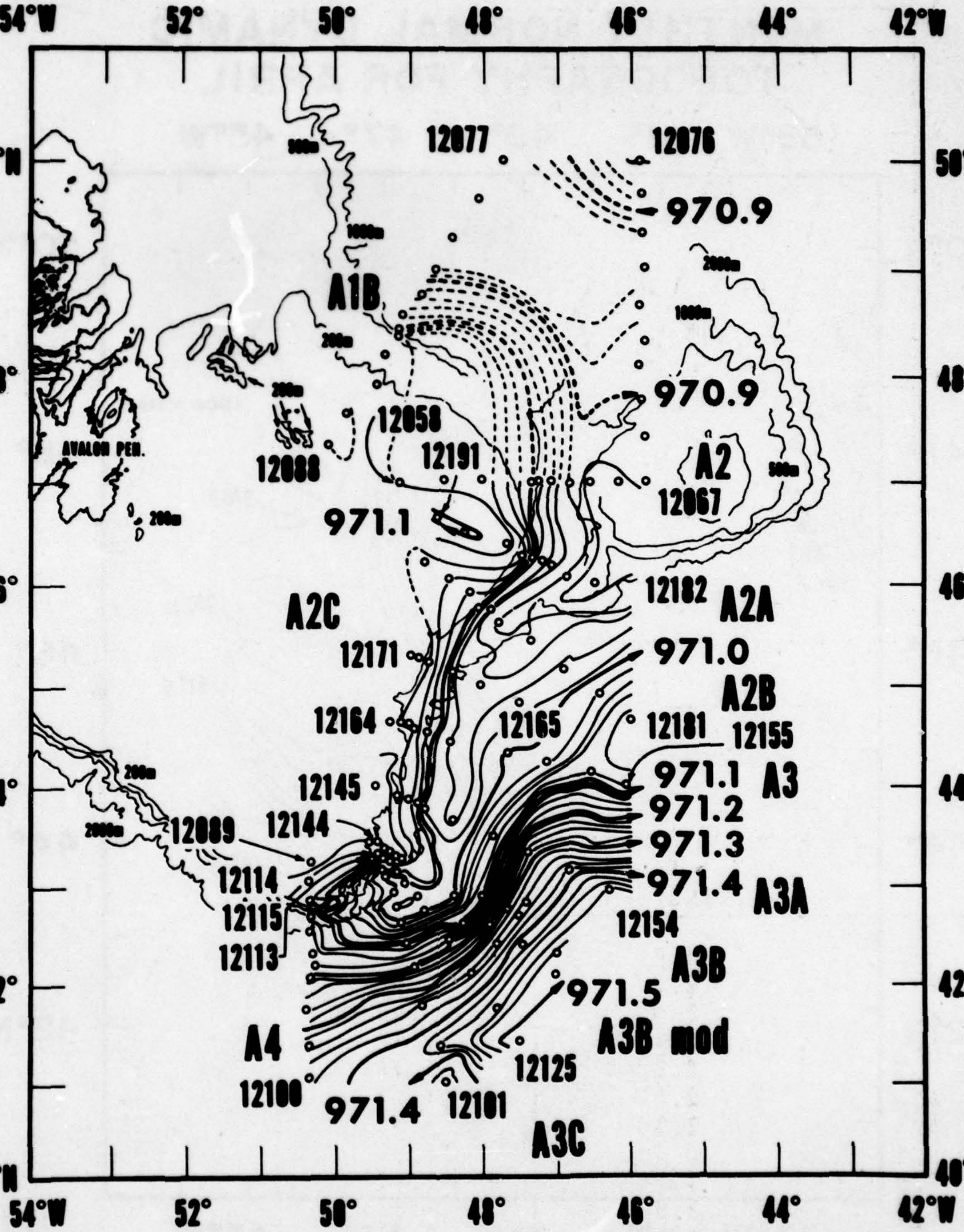
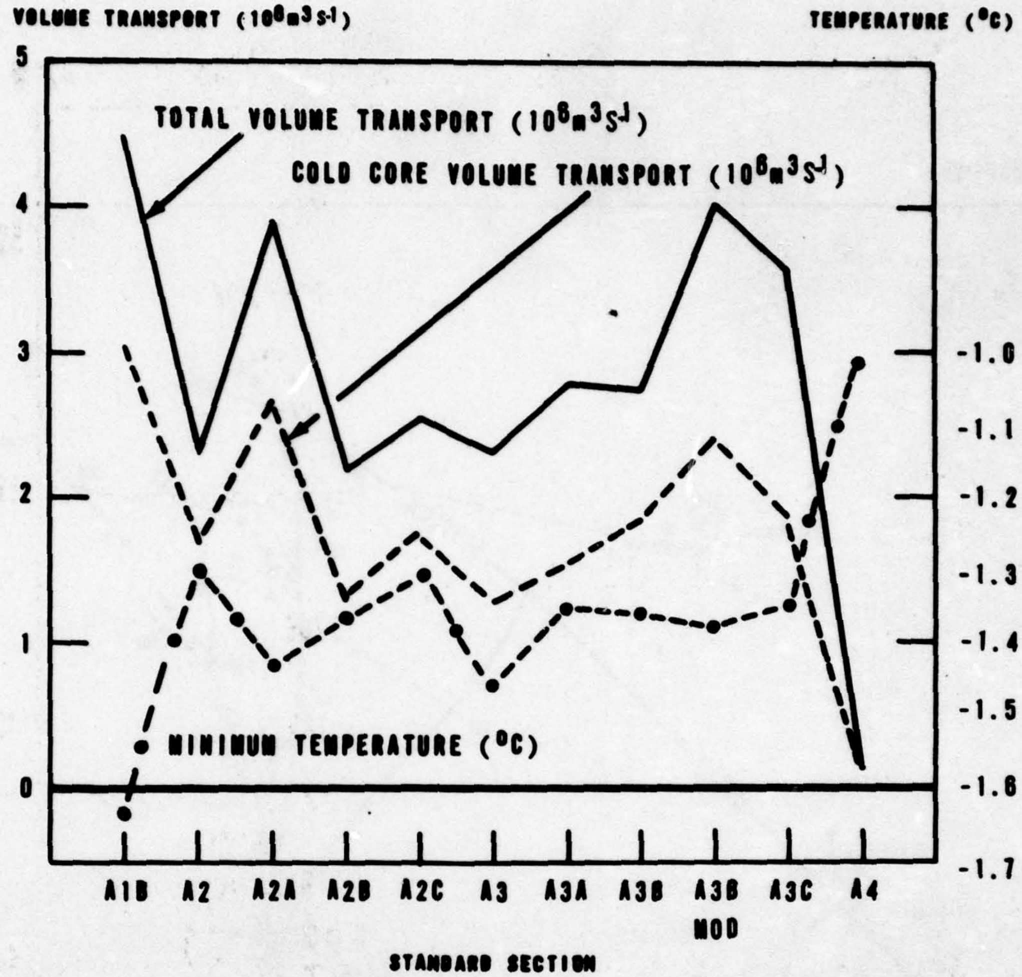


FIGURE 27.—Sea surface dynamic topography (dynamic meters) relative to the 1,000 decibar level, CGC EVERGREEN, 8–20 June 1976. Contour interval is 2 dynamic centimeters



	TOTAL VOLUME TRANSPORT	COLD CORE TRANSPORT	MINIMUM TEMPERATURE
A1B	4.47	3.04	-1.63
A2	2.30	1.70	-1.30
A2A	3.90	2.65	-1.43
A2B	2.19	1.28	-1.36
A2C	2.53	1.74	-1.30
A3	2.30	1.27	-1.46
A3A	2.79	1.53	-1.35
A3C	2.75	1.87	-1.36
A3B MOD	4.02	2.41	-1.38
A3C	3.56	1.87	-1.35
A4	0.13	0.08	-1.04

FIGURE 28.—Comparisons of total volume transport, Cold Core volume transport, and minimum temperatures during the full dynamic topographic survey, 8–20 June 1976

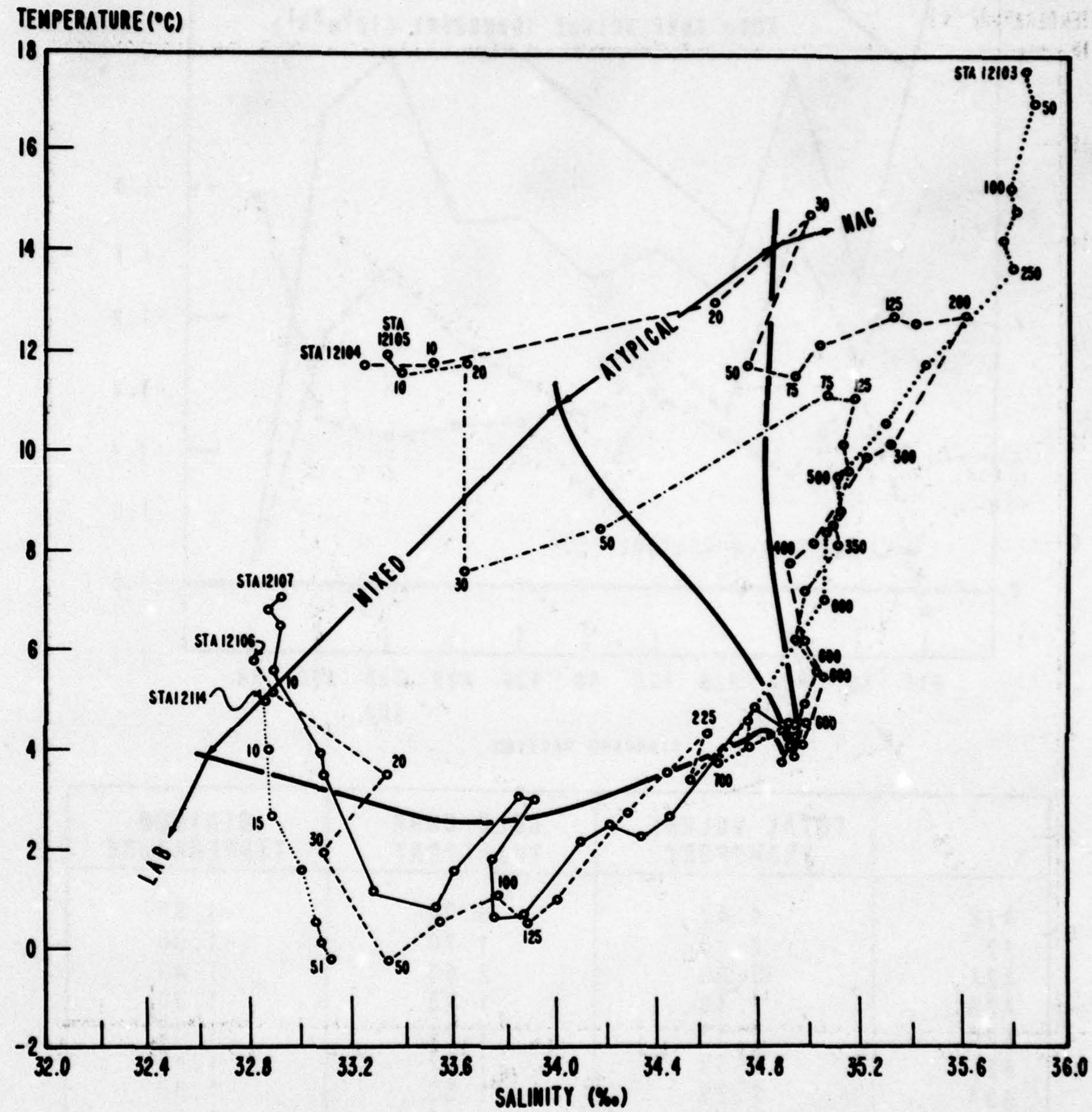


FIGURE 29a.—Temperature—Salinity diagram of selected stations for section A3C, 9–11 June 1976

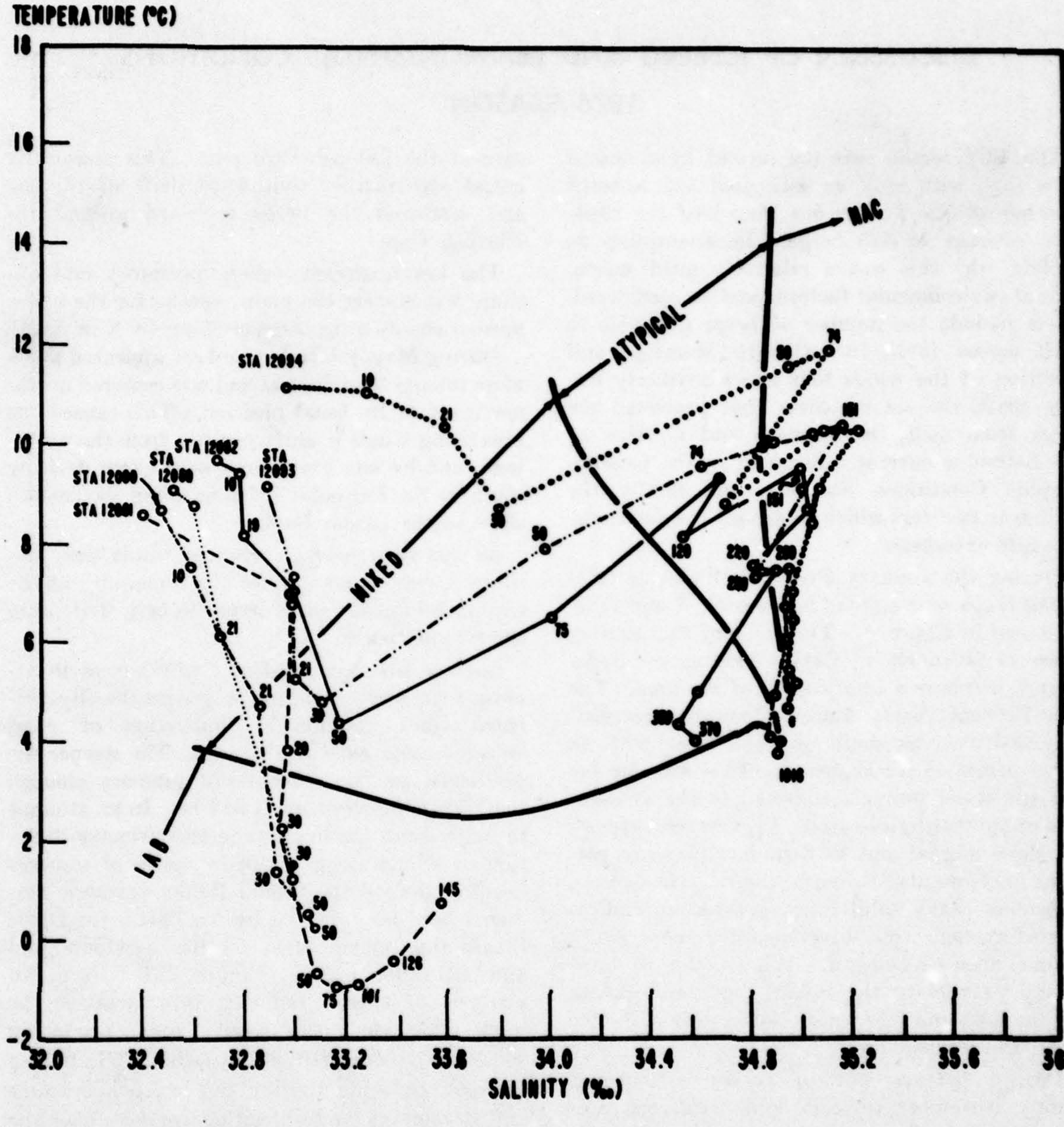


FIGURE 29b.—Temperature—Salinity diagram of selected stations for section A4, 6–9 June 1976

DISCUSSION OF ICEBERG AND ENVIRONMENTAL CONDITIONS 1976 SEASON

The 1976 season was the second light season in a row, with only an estimated 151 icebergs crossing 48°N. This is less than half the 1946–1975 average of 315 bergs. In attempting to explain why this was a relatively mild season, several environmental factors must be considered. These include the number of bergs available to drift across 48°N, the strength, duration and direction of the winds that affect southerly iceberg drift, the sea ice cover that protected the bergs from melt, the strength and position of the Labrador current (discussed in the Oceanographic Conditions Section), and finally the various parameters which determine the deterioration rate of icebergs.

During the January Preseason flights, a total of 563 bergs were sighted between 53°N and 71°N as shown in Figure 1. The January flights were flown as far north as Cape Christian on Baffin Island to ensure a total census of the area. The late February/early March Preseason revealed only 303 icebergs south of Cape Dyer with no bergs below 48°N, Figure 4. This was far below statistical normals and lead to the expectation of another light season. Figures 30a through 30l show normal and 1976 surface pressure patterns for November through August. The isobars, shown as heavy solid lines, provide an indication of average wind direction for a given month in our area of concern. Winds tend to blow nearly parallel to the isobars, counterclockwise for a low and clockwise for a high in the Northern Hemisphere.

During the early part of the season, approximately November through mid-April, the predominant map feature was an abnormally positioned and unusually intense Icelandic Low. This deviation produced strong to moderate surface winds from the west and west-northwest south of 52°N. With these winds and the resulting wind-driven currents, bergs approaching the Grand Banks were driven to the east out of the core of the Labrador Current. This essentially ended any further southward drift of this ice and scattered the bergs eastward around the Flemish Cap.

The low upstream iceberg inventory and offshore winds were the main reasons for the below normal counts of icebergs crossing 48°N in April.

During May, the Icelandic Low appeared much more intense than normal and was centered north-northeast of its usual position. This caused the prevailing winds to shift, coming from the northwest, and by late May bergs were again drifting south in the Labrador Current along the eastern slope of the Grand Banks.

As has been normal, average winds were onshore during June and for the remainder of the season, inhibiting any further iceberg drift onto the Grand Banks.

Surface pressure gradients (differences in atmospheric pressure along a geographically oriented line) provide an indication of wind velocities that exist in the area. The steeper the gradients, or the more rapid pressure change, the higher the wind speed will be. In an attempt to understand the magnitude and primary direction of winds along the main routes of icebergs heading toward the Grand Banks, six such gradients have been defined by Ice Patrol for Davis Strait and certain areas off the Newfoundland and Labrador coasts (Figure 31). From an analysis of these gradients, inferences can be made about the northwesterly winds producing southerly iceberg drift, accentuating the Labrador Current, reducing the air and sea temperatures and developing and spreading sea ice along the coasts of Labrador and Newfoundland.

Gradients assigned numbers 1 and 2 in Figure 31 indicate the intensity of the north/south components of the winds off the Labrador coast. These winds are important in assisting or impeding the drift of icebergs toward the Grand Banks.

Gradient 3 measures the north/south wind component along the eastern slope of the Grand Banks which is partially responsible for determining the speed at which icebergs will drift south in this area. Gradient 4 is a measurement of the influence of westerly, or easterly, winds along the northern slope of the Grand Banks. These winds are important in determining iceberg drift toward or away from the Newfoundland coast and into or out of the core of the Labrador Current. If the westerly winds are too strong or persistent when the bergs reach the northeast corner of the Grand Banks, they may be carried over Flemish Cap and deteriorate rapidly as they are pushed into the warmer waters of the North Atlantic Current. Gradients 5 and 6 provide a preseason indication of the potential for iceberg drifts south and west in Davis Strait.

The 1976 pressure gradient statistics are shown graphically in Figure 32 in comparison with their 1946–1975 averages. Gradients 1 and 2 show above normal southerly flows throughout the season, with lulls in the December, January and April positions of each graph before normalizing or going slightly below normal in July. This provided a great impetus for southerly iceberg drift during the season. Icebergs did not reach gradient areas 3 and 4 until early March. From then until mid-June, the gradient pressure rose to slightly above normal, thereby increasing southerly flow slightly. Gradient 4 shows a predominant easterly wind flow until mid-June, which kept the bergs drifting mainly in the Labrador Current along the eastern slope of the Grand Banks. Gradients 5 and 6 combined show a general south-easterly flow, from September through November, then changing to a predominant northerly flow inhibiting berg movement into the Davis Straits until February when both gradients basically normalized.

Air temperatures throughout the season were normal with the exception of northern Labrador and Baffin Island where temperatures fell to approximately 6–8°F below normal in January and February. A frost degree day, as used in Figure 33, is defined as one day at a temperature of one fahrenheit degree below 32°F i.e. one day at 20°F would be 12 frost degree days). Similarly, a melting degree day is one day at a temperature of one fahrenheit degree above 32. All stations illustrated showed slightly above normal frost degree days and slightly below normal melt degree days. These near normal temperatures combined with the far less than normal southern expanse of sea ice this year were in a large part responsible for limiting the number of icebergs that survived to reach the Grand Banks region, resulting in a relatively light season.

Figures 34 and 35 depict sea surface temperature (°C) contours for two representative periods during 1976. Contours provided by the Meteorology and Oceanography Office (METOC) of Canadian Maritime Command (MARCOM) have been modified by additional data received by Ice Patrol from merchant shipping and Airborne Radiation Thermometer (ART) surveys. Since the latter part of the 1974 ice season, Ice Patrol observers have been using the ART to record sea surface temperatures while conducting aerial ice reconnaissance. The operational use of the ART has been described in Appendix C of the 1974 Ice Patrol Bulletin (CG–188–29) and is discussed further in Appendix E of this Bulletin. The late April temperatures in 1976 were just slightly warmer than normal and early July sea surface temperatures were approximately 1°C below normal. This corresponds well with the melt degree day records for St. John's presented in Figure 33 showing April's accumulation greater than normal and both June and July's below normal.

The following iceberg melt table was developed from observations made by Lenczyk (1962–1964). The International Ice Patrol uses this table to predict the complete melt of various sized icebergs.

Temperature (°)	*Growler and Small Iceberg (Height 1–15m Length 6–60m*	*Medium Iceberg (Height 16–45m Length 61–122m)*	*Large Iceberg (Height 46+ meters Length 123+ meters)*
0	—	—	—
2	9 days	17 days	38 days
4	6 days	11 days	23 days
6	4 days	8 days	16 days
8	3 days	6 days	13 days
10	3 days	6 days	11 days
12	3 days	5 days	9 days
14	2 days	4 days	8 days

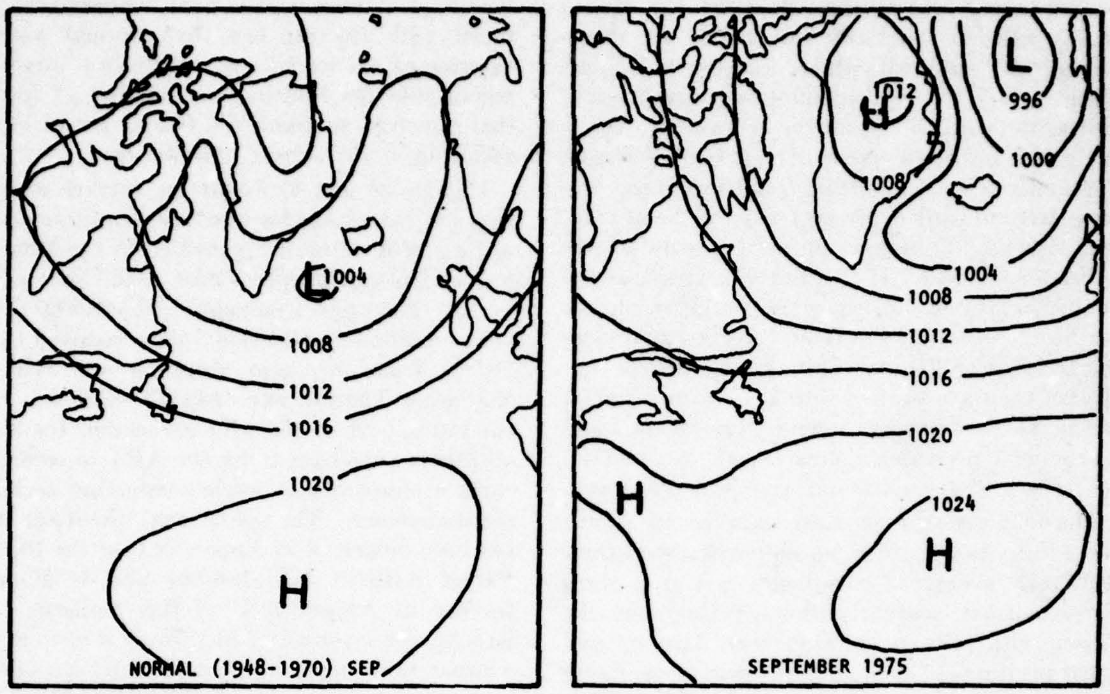


FIGURE 30a.—September Normal and 1975 Monthly Average Surface Pressure in mbs

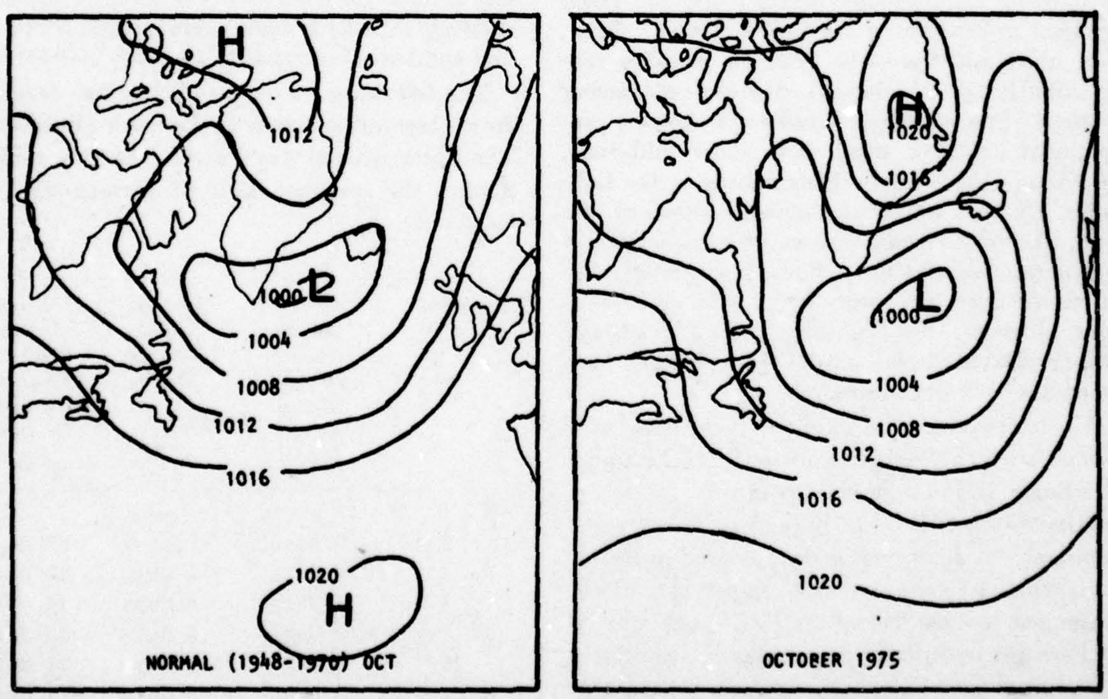


FIGURE 30b.—October Normal and 1975 Monthly Average Surface Pressure in mbs

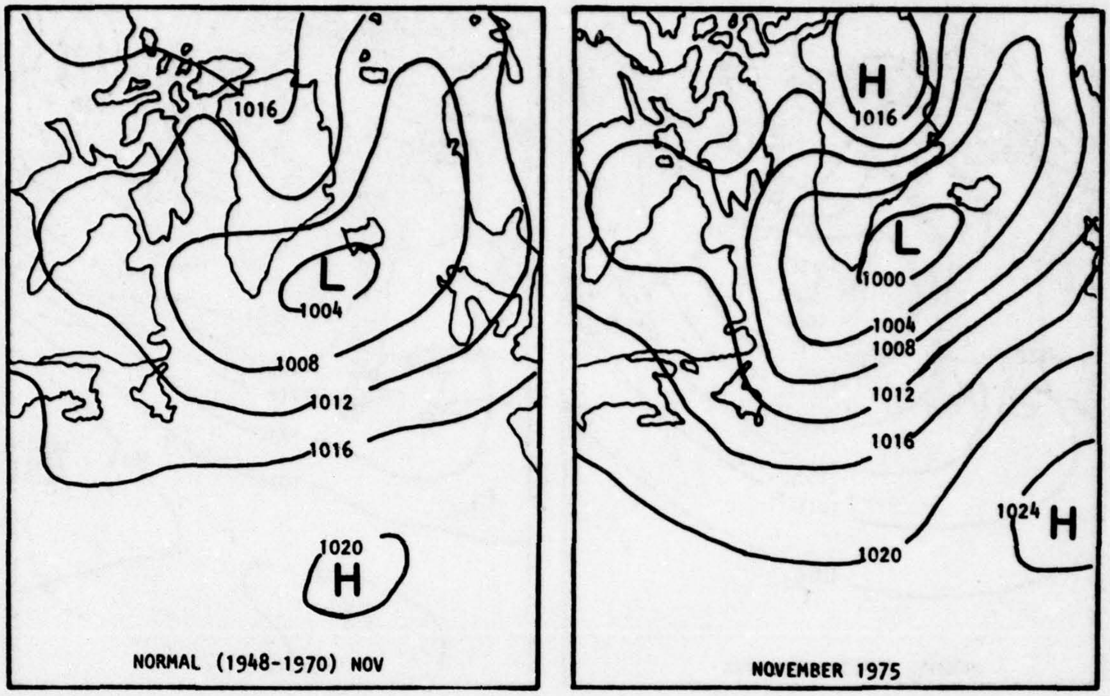


FIGURE 30c.—November Normal and 1975 Monthly Average Surface Pressure in mbs

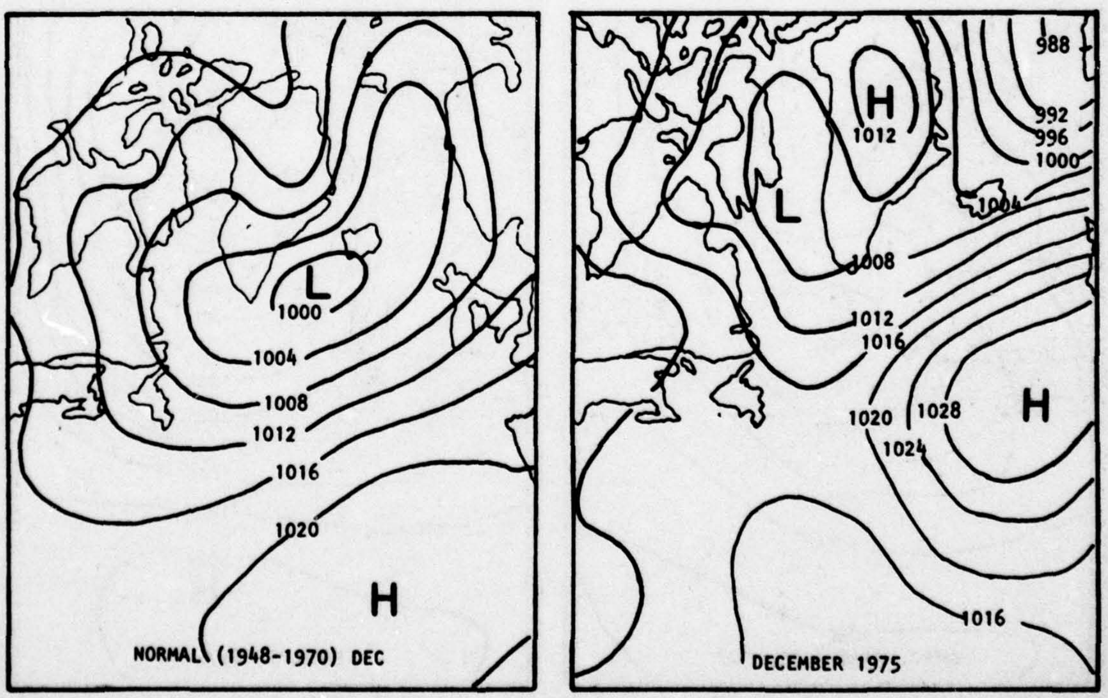


FIGURE 30d.—December Normal and 1975 Monthly Average Surface Pressure in mbs

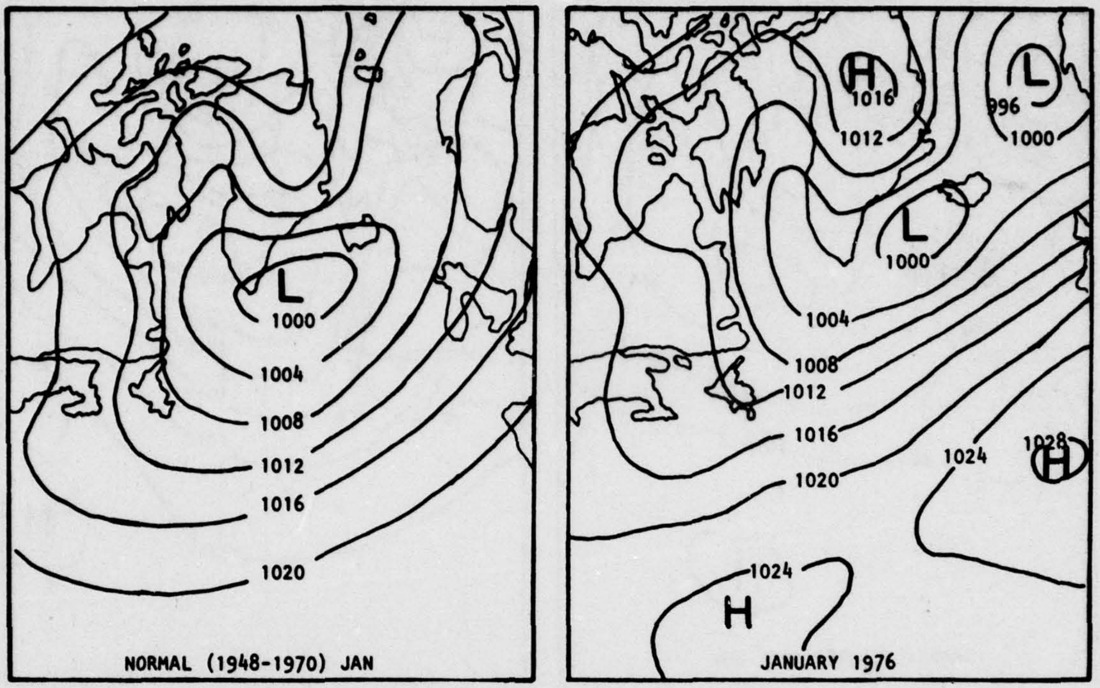


Figure 30e.—January Normal and 1976 Monthly Average Surface Pressure in mbs

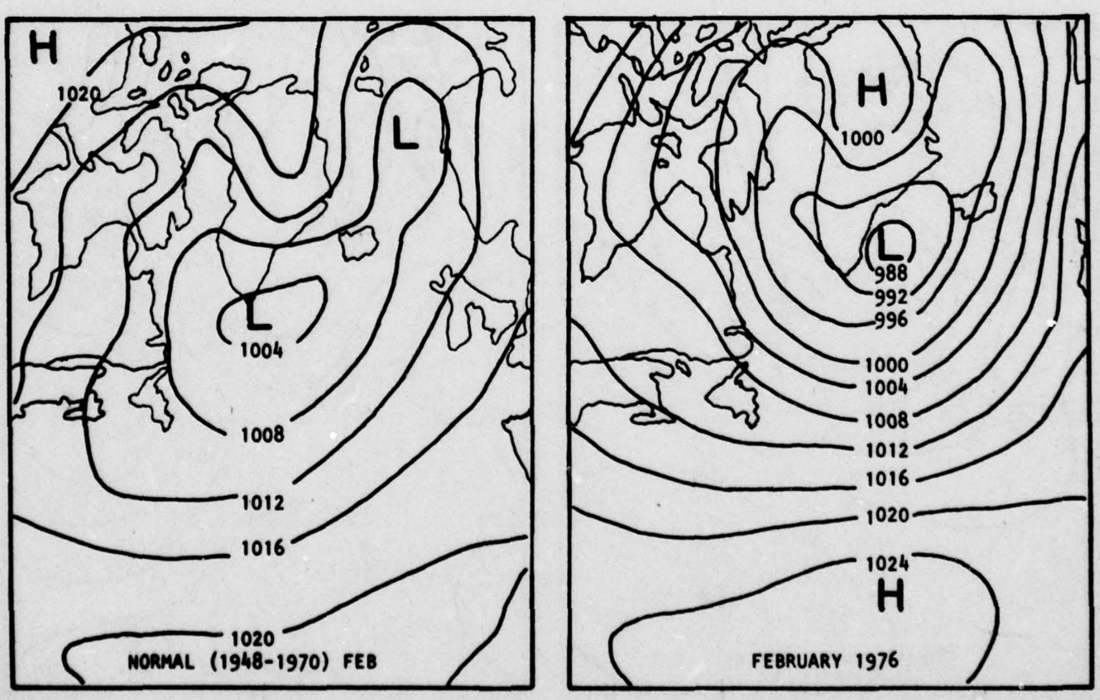


Figure 30f.—February Normal and 1976 Monthly Average Surface Pressure in mbs

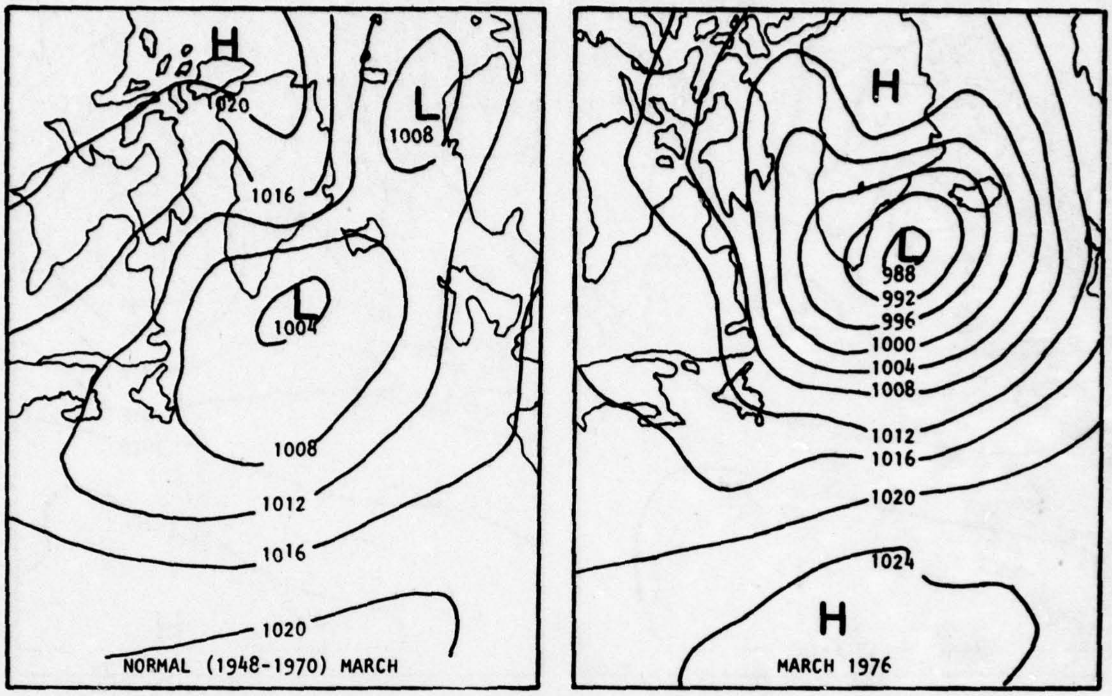


Figure 30g.—March Normal and 1976 Monthly Average Surface Pressure in mbs

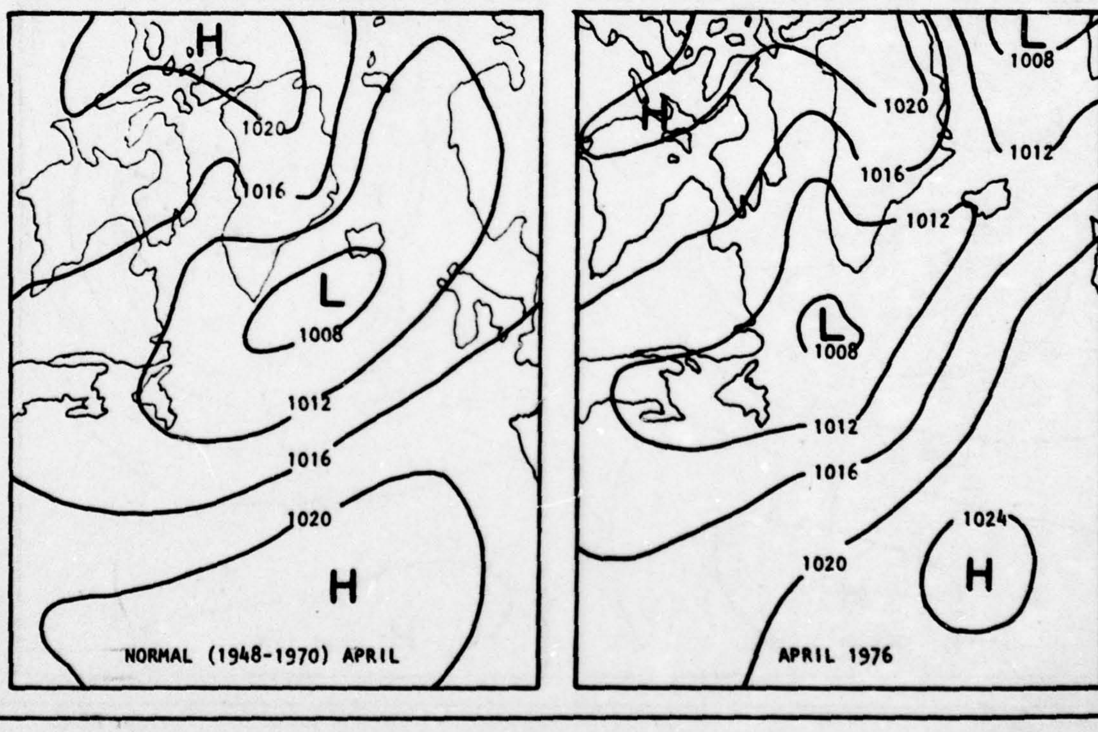


Figure 30h.—April Normal and 1976 Monthly Average Surface Pressure in mbs

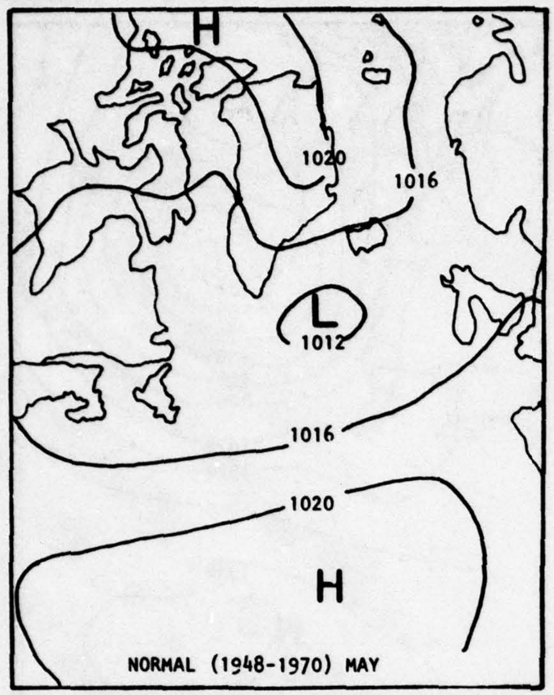


FIGURE 30i.—May Normal and 1976 Monthly Average Surface Pressure in mbs

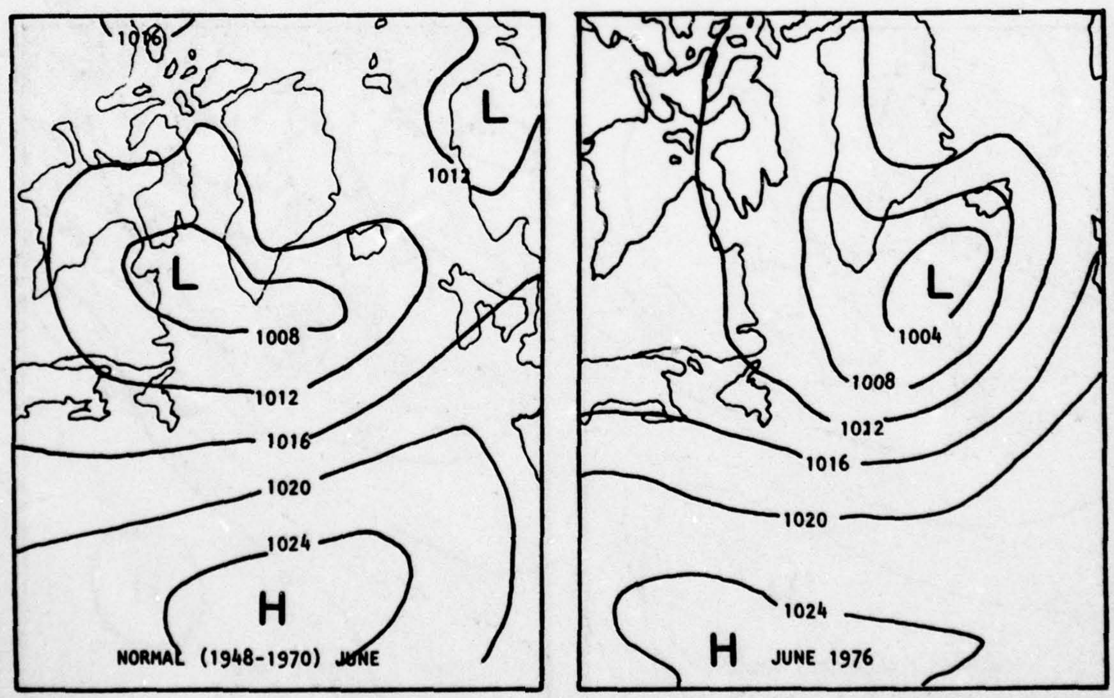


FIGURE 30j.—June Normal and 1976 Monthly Average Surface Pressure in mbs

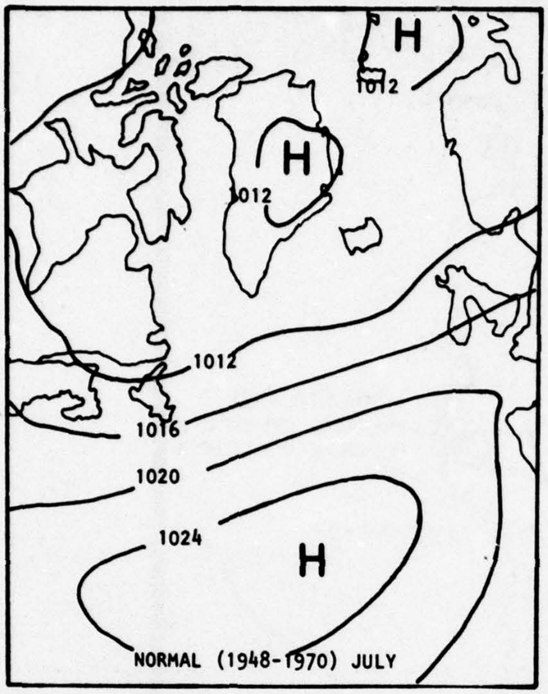


FIGURE 30k.—July Normal and 1976 Monthly Average Surface Pressure in mbs

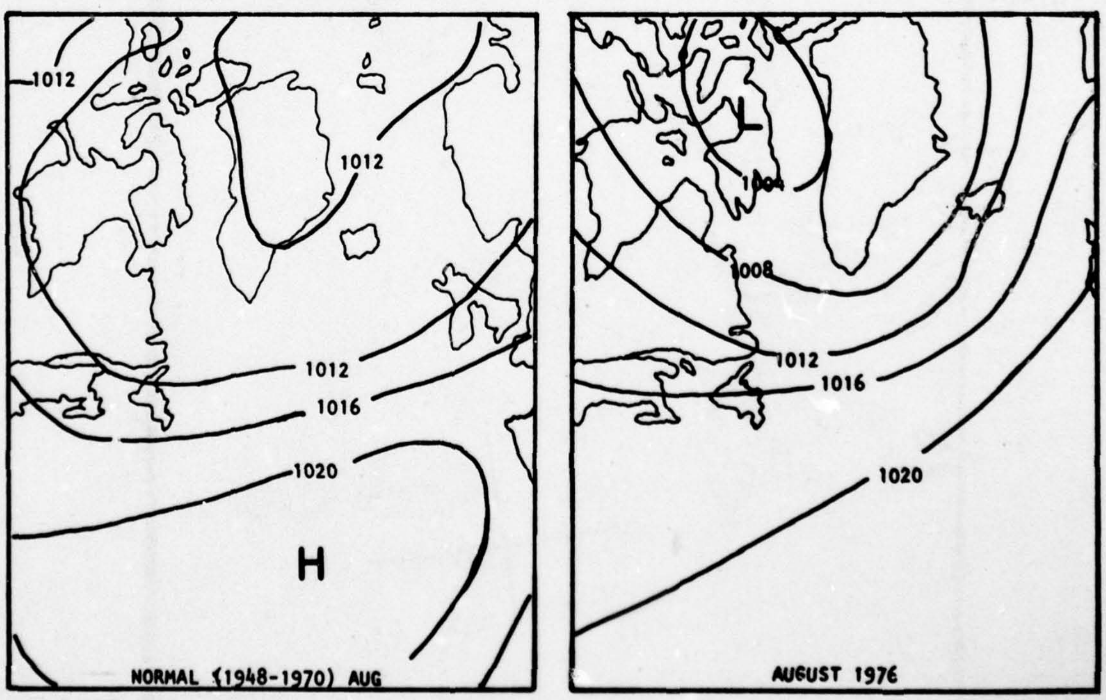


FIGURE 30l.—August Normal and 1976 Monthly Average Surface Pressure in mbs

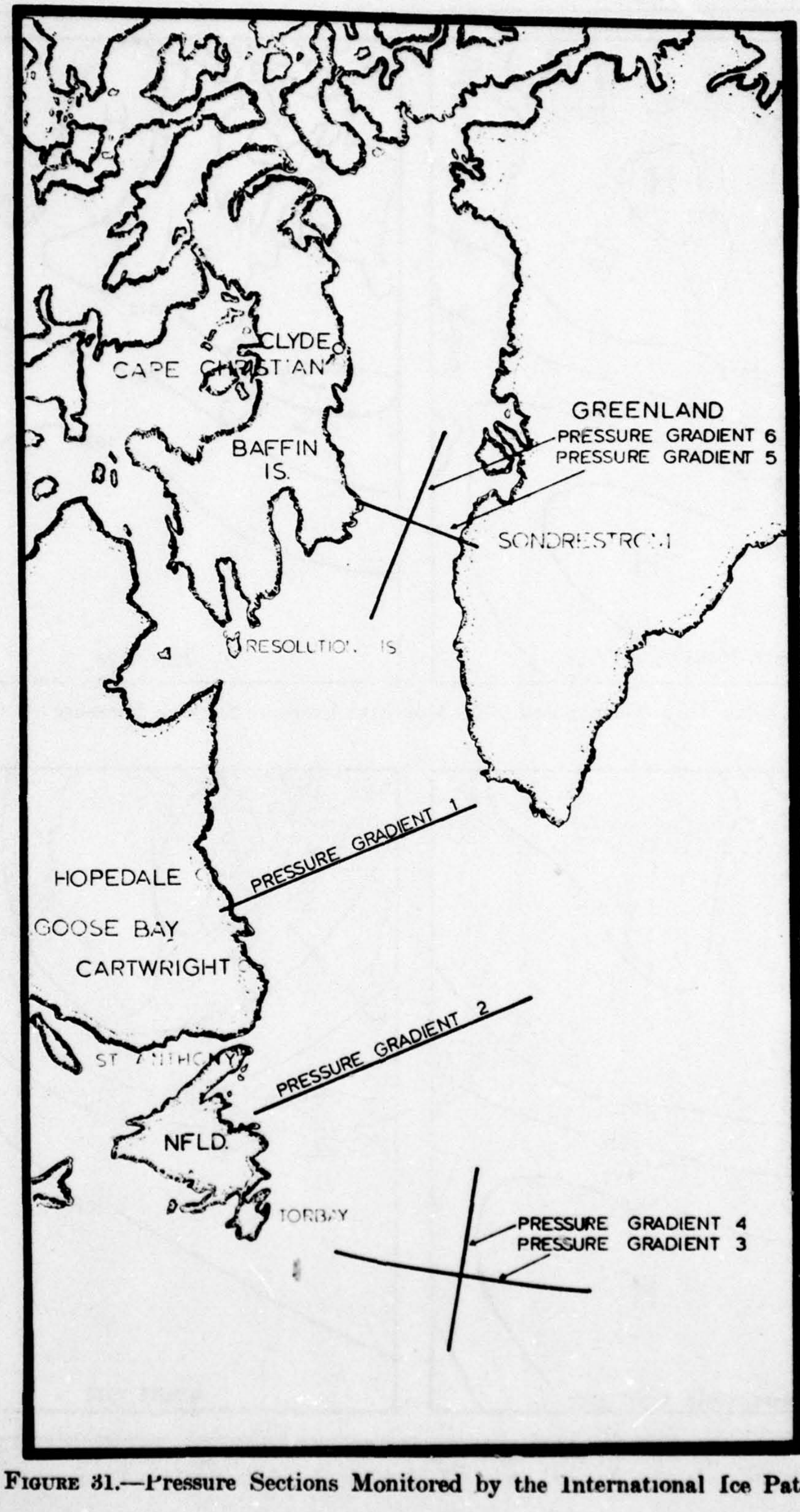


FIGURE 31.—Pressure Sections Monitored by the International Ice Patrol

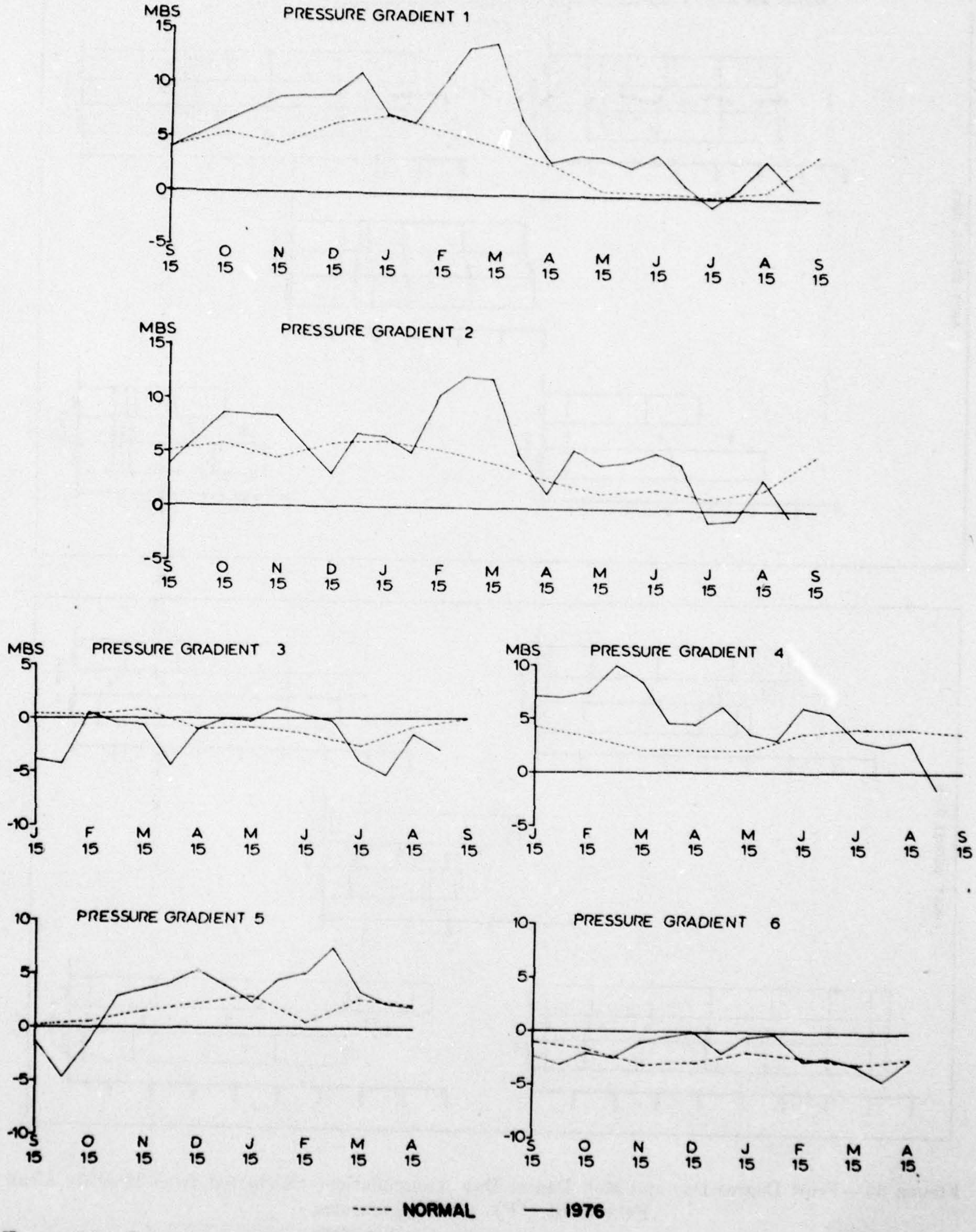


Figure 32.—Comparison of the Normal Pressure Gradient to those recorded during the 1976 ice season on Section 1 thru 6

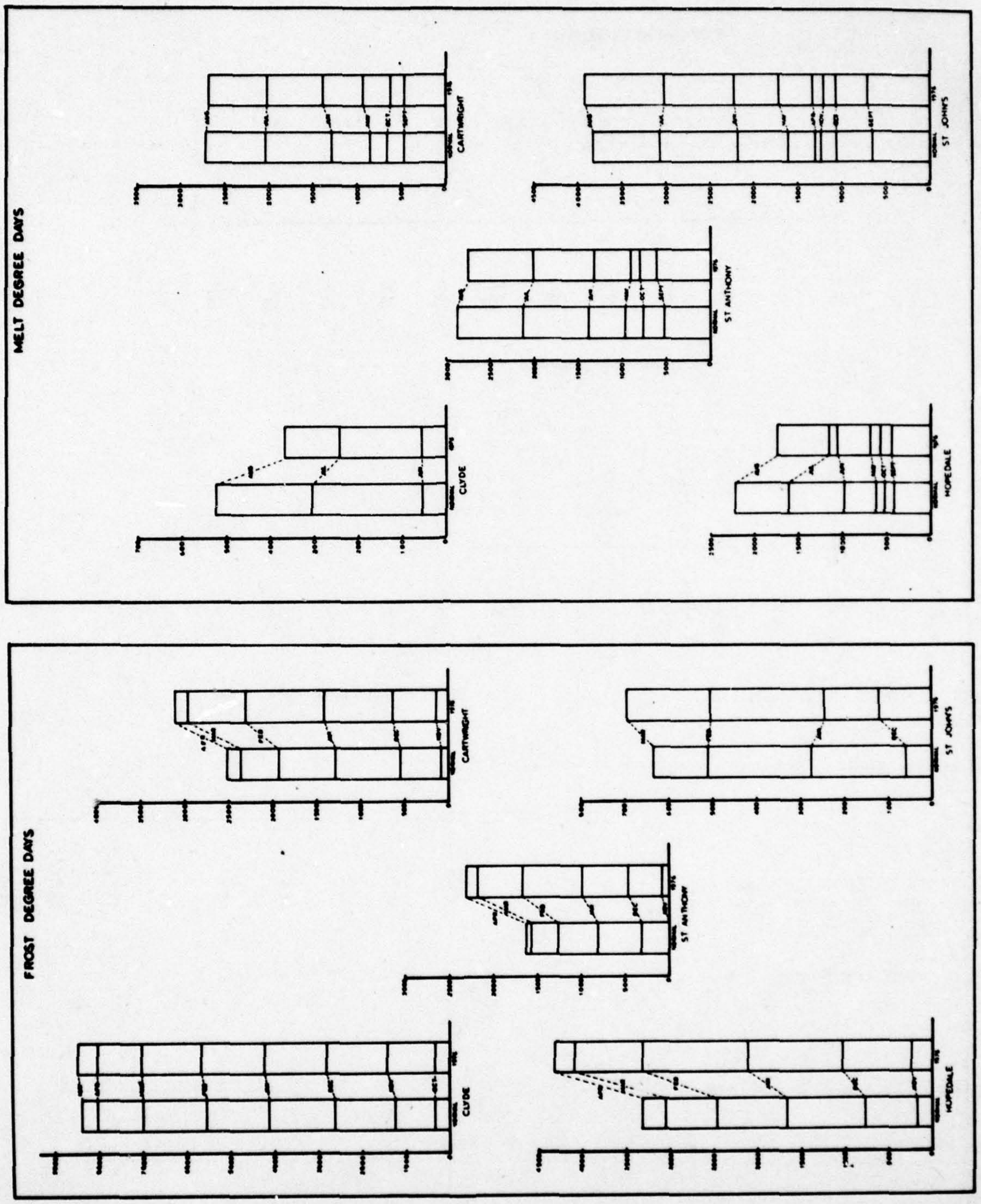


FIGURE 33.—Frost Degree Day and Melt Degree Day Accumulations Calculated from Monthly Mean Fahrenheit (°F) Air Temperatures

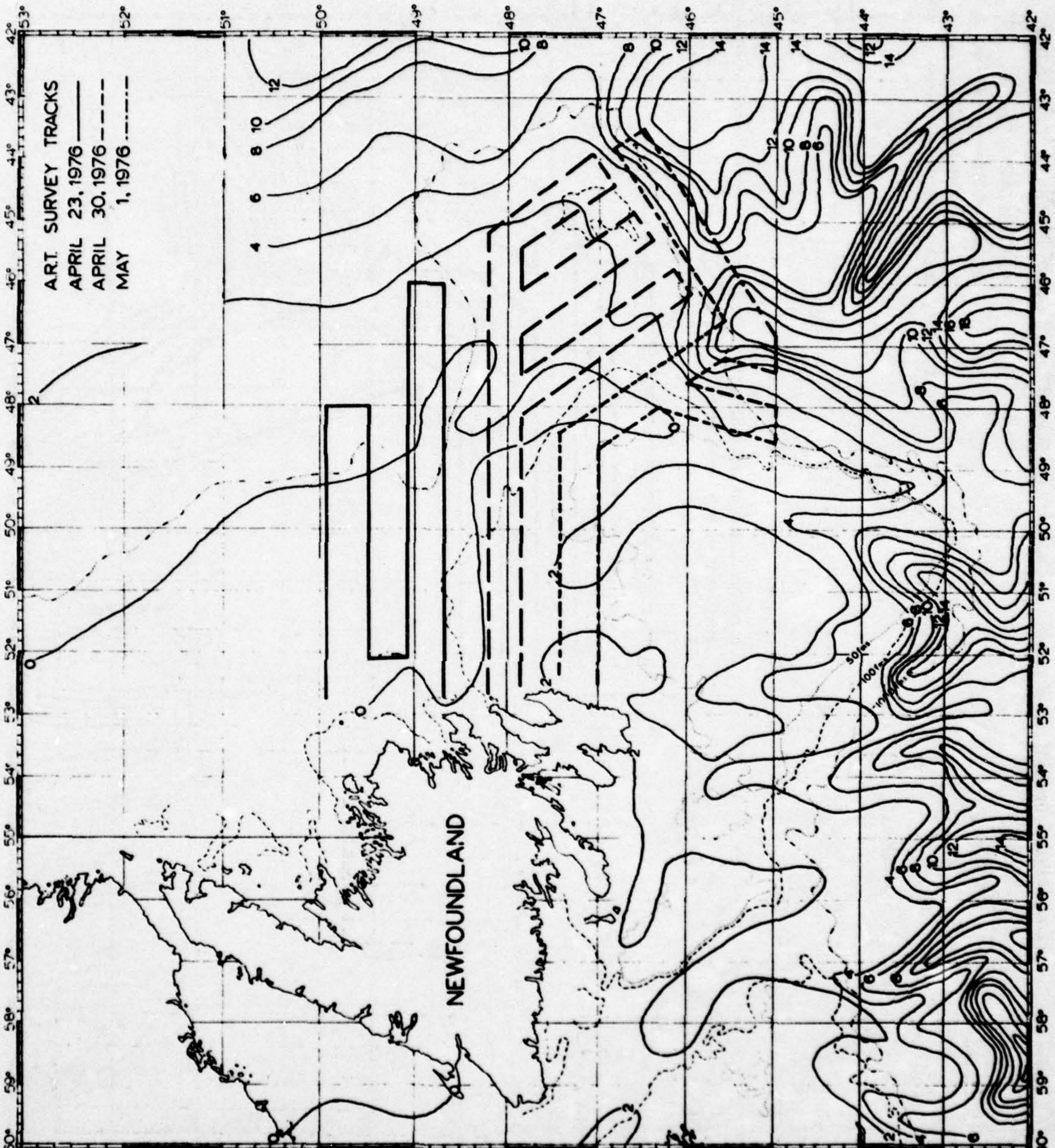


Figure 34.—Sea Surface Temperature Contours (°C) developed from Airborne Radiation Thermometer (ART) surveys conducted on 23 and 30 April and 1 May 1976

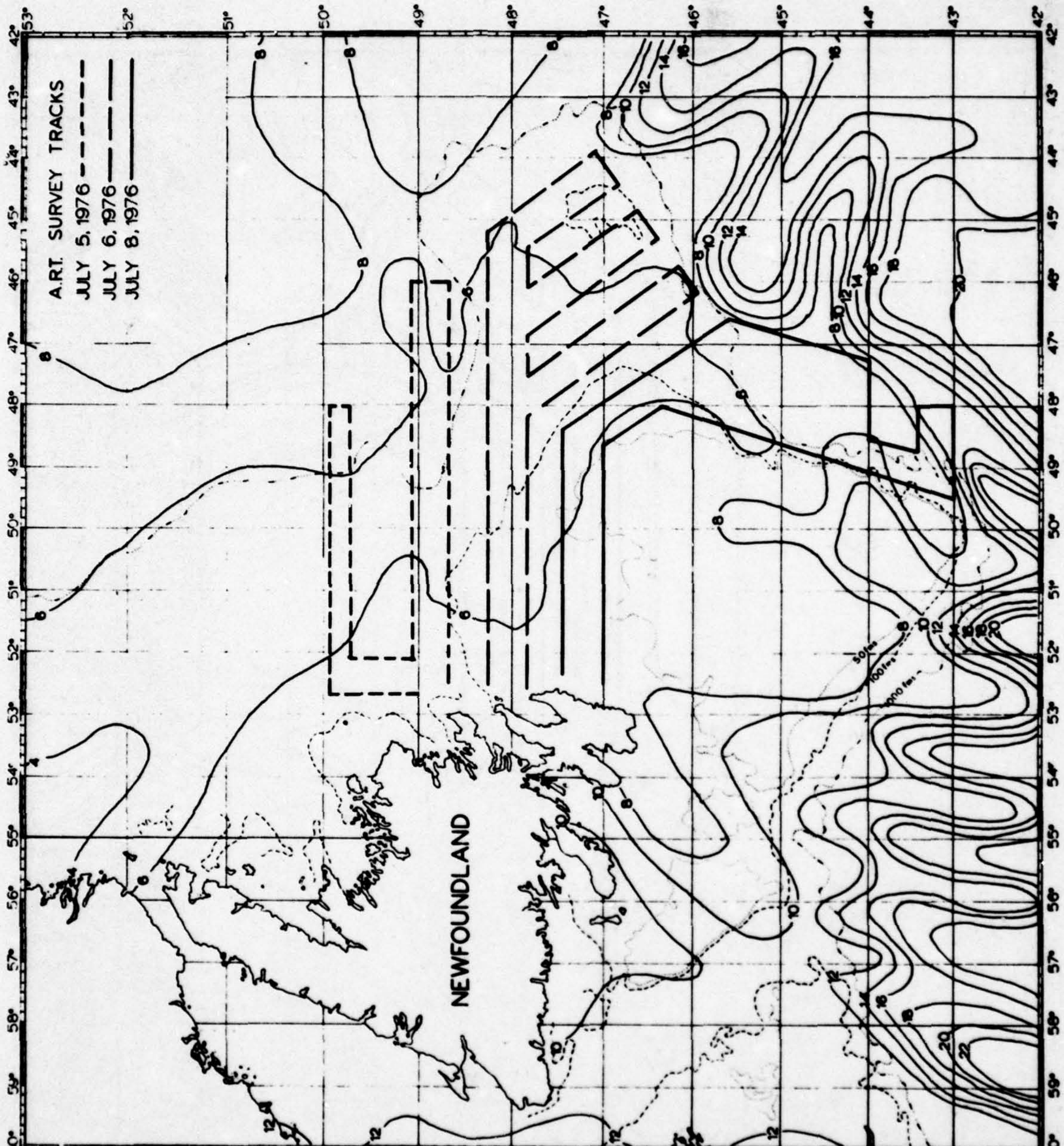


Figure 35.—Sea Surface Temperature Contours (°C) developed from Airborne Radiation Thermometer (ART) surveys conducted on 5, 6 and 8 July

RESEARCH AND DEVELOPMENT, 1976

During 1976, the IIP research and development effort was centered on the collection of iceberg drift date, gathering of current information near the Tail of the Banks, and further development of remote sensing equipment.

The iceberg drift data endeavor was designed to provide the velocities of the iceberg, current and wind. Current velocity was obtained by using a newly designed integrating current drogue. The drogue made use of multiple window shade drogue panels to measure the total current affecting the iceberg. The surface float/marker used a newly acquired X-Band radar transponder which marked the radar screen with a unique symbol for easy identification. Detailed drifts were obtained for time periods up to 60 hours.

An unsuccessful attempt was made to measure the current field east of the Tail of the Banks. Three moorings at the corners of an equilateral triangle were to provide information on eddies, meanders and rings of the Labrador/North Atlantic Current system. The moorings were deployed without difficulty, but were not recovered due to an unknown equipment malfunction.

A photographic survey of Grand Banks icebergs was conducted with an aerial mapping camera. One result of this survey was a series of fine photographs of the same tabular iceberg over a time period of 24 days (See Appendix B). The deterioration processes acting on the iceberg were clearly evident.

Remote sensing test and evaluation was conducted with the continuation of a cooperative NASA Lewis Research Center-International Ice Patrol program to develop an all-weather iceberg detection and identification system. Side-Looking Airborne Radar (SLAR/APS-94C) was the primary instrument used and was found to be an extremely reliable detection device. The problem remains with identification of the detected targets (i.e., ship vs. iceberg, surface debris vs. iceberg, sea ice vs. iceberg). Attempts were made to use ECM (Electronic Counter Measure) equipment. It was hoped that the ECM would be able to detect shipboard radar transmissions and thus identify certain targets as ships. Problems in accurately determining the direction from which signals originated and the realization that a number of ships, particularly fishing vessels, often operated without radar, proved to make this system unreliable. SLAR remains the device providing the most potential for solving Ice Patrol's problems of tracking icebergs in the adverse weather conditions so prevalent in the vicinity of the Grand Banks.

Over-the-Horizon Radar (OHR) was evaluated for iceberg detection using the MADRE system of the Chesapeake Naval Research Laboratory. It was determined that the present state-of-the-art does not provide sufficient resolution to meet the need of the Ice Patrol.

ICE AND SEA SURFACE TEMPERATURE REPORTS RECEIVED FROM SHIPS OF PARTICIPATING NATIONS DURING 1976

	ICE	SST
BELGIUM		
FEDERAL SCHELDE	2	
FEDERAL ST LAURENT	1	
CANADA		
HURON		6
IMPERIAL QUEBEC	2	
NIPIGON		18
CHILE		
CHOAPA	2	2
DENMARK		
AVALON	1	
LOUIS MAERSK	1	
NINA LONBORG	1	
NORTHERN	1	
PACIFIC SKOU	1	
ROSA DANIA	1	
SAMOAN REEFER	1	
TORM ESTRID		1
EAST GERMANY		
ALSTER EXPRESS	1	
BETAGAS	1	
BRUNSWICK		12
ELBE EXPRESS	1	
NORDIC	1	
PROSERPINA		1
THOR	1	
TILLY ROSS	1	
FINLAND		
FORANO		9
FRANCE		
DELCHIM ALSACE		5
FRANCOIS L D	1	
GREAT BRITAIN		
ALBRIGHT PIONEER	1	
ALTENOR	1	2
ARCTIC TROLL	1	3
ARDMORE		4
ATLANTIC CAUSEWAY	1	
ATLANTIC CONVEYOR	1	

	ICE	SST
GREAT BRITAIN—Continued		
BRIMNES		3
CAST BEAVER	1	
C P DISCOVERER	5	
C P TRADER	14	
C P VOYAGUER	3	
DART AMERICA	2	1
DART ATLANTIC	1	1
ESKDALEGATE		28
FRINTON	1	
KING CHARLES	1	
KING JAMES	1	
MANCHESTER CHALLENGE	3	
MANCHESTER CONCORDE	10	7
MANCHESTER CRUSADE	1	
MONKSGARTH	1	
M S LAURENTIAN	1	
QUEEN ELIZABETH	2	
QUEENSGARTH	4	
RESOURCE		1
SILVERTWEED	1	
SUGAR TRANSPORTER	1	1
VANCOUVER TRADER	2	
GREECE		
ALTHEA	1	
NIKOT	1	
ICELAND		
BAKKAFOSS	10	56
BRUARFOSS	2	1
SELFOSS	3	1
ITALY		
GALLASSIA		5
LEONARDO DA VINCI		1
JAPAN		
EUROPEAN HIGHWAY	1	
KOREA		
WHITE ROSE	1	
KUWAIT		
AL ARIDHIAH	6	

	ICE	SST
LIBERIA		
ARTADI		8
ASIA FLAMINGO		1
FALCONDALE	1	
GARDEN SUN		7
GLORIC	1	
KONKAR INTREPID		1
MASTER JANEY	1	
MELTIMI		7
OGDEN CLIPPER	1	
OGDEN THAMES	1	
ORE METEOR		1
NETHERLAND		
ANTARCTIC	1	
DORDRECHT	1	
THUREDRECHT	2	
WITTI ZEE	1	
NORWAY		
BANAK	1	
BELCARGO	1	
BRUNHORN	1	
FALCON	1	
FERNLEAF		2
GARD	1	5
HANSA BAY	1	
IDEFJORD	2	
JAWAGA	1	
JOADA	1	
JOBEBE	1	
PANAMA		
HUMBERT	1	
PARAGUAY		
PEKARI	1	
POLAND		
STEFAN BATORY	1	
ZAMBRZE	2	

	ICE	SST
SENEGAL		
PAN TECK		5
SINGAPORE		
ANDROMED	1	
KONKORDIA	1	
SWEDEN		
ARIEL	1	
ATLANTIC SAGA		3
ATLANTIC SPAN		31
GUNNAR CARLSON	1	
IRISH WASA		6
MILES	1	
MONTROYAL	19	1
RAGNA GORTHON		4
SEGERO	1	
UNITED STATES OF AMERICA		
KNORR	2	
NEPTUNE		3
PIEDMONT		3
PUGET SOUND		5
UNITED STATES COAST GUARD		
USCGC EVERGREEN	15	1406
USCGC NORTHWIND	95	110
USCGC SHERMAN	33	96
USCGC WESTWIND	3	1
UNITED STATES NAVY		
USNS MIRFAK	1	1
WEST GERMANY		
ANTARES	6	
TUBINAR		1
YUGOSLAVIA		
BOSANKA NO. 1		6

APPENDIX A

SIZE FREQUENCY DISTRIBUTION OF GRAND BANKS ICEBERGS

R. Q. ROBE

U.S. Coast Guard Research and Development Center

Historically, iceberg counts have been made by an IIP estimate of the total number of iceberg and growlers along the eastern Canadian coast and the Grand Banks. Of necessity, very little attention was given to the accurate determination of size. Tabular icebergs were categorized (Murray, 1968) as large (height greater than 50 ft.; length greater than 700 ft.), medium (height 20–25 ft.; length 300–700 ft.) and small (height to 20 ft.; length less than 300 ft.). All shapes other than tabular were categorized as very large (height greater than 255 ft.; length greater than 700 ft.), large (height 150–255 ft.; length 400–700 ft.), medium (height 50–150 ft.; length 200–400 ft.), small (height less than 50 ft.; length less than 200 ft.). Although the ice observers are highly trained, their estimates are subjective. They must rely only on a practiced eye to place a berg in one of the above categories. This requires that they estimate range to the berg and then evaluate its relative size against a background of ice or water, neither of which offer any known object for size comparison. This estimation is conducted at various flight levels, sun angles, and visibilities. As a result, size estimations result in a poor quantitative size distribution and are not useful for a detailed study of iceberg sizes.

With the advent of remote sensing possibilities for iceberg detection, a more quantitative distribution for iceberg sizes is needed. In order for such systems as SEASAT and SLAR (Side-Looking Airborne Radar), with their greater all weather detection capability, to be used to full advantage, information on the population they are sampling must be available.

During the 1976 IIP season a CA-14 aerial mapping camera was placed aboard the Ice Patrol aircraft for a period of 47 days. On these flights, a total of 104 icebergs and growlers were photographed. Altitudes for the photographic flights ranged from 1,000 ft. to 11,000 ft. The area covered by the photographed icebergs was between 44°N and 51°N and 45°W and 51°W. Icebergs were photographed on a not to interfere basis with the aircraft's primary mission of iceberg reconnaissance. Therefore, the sample does not represent the totality of icebergs in the area covered. Growlers of less than $10m^2$ were not counted.

The frequency of icebergs versus horizontal cross-sectional area (Figure A–1) indicates a very strong peak for the small sizes. Icebergs less than $1{,}000m^2$ (but greater than $10m^2$) account for 53 of the 104 icebergs in the sample. The frequency drops off rapidly as size increases. Icebergs in the interval $1{,}000m^2$ to $2{,}000m^2$ included only 12 icebergs and the range $2{,}000m^2$ to $6{,}000m^2$ 22 icebergs. Only 17 of the 104 icebergs were larger than $6{,}000m^2$.

SEASAT-A which is due to be launched in 1978 will carry a SAR (Synthetic Aperature Radar) with a resolution of approximately 25m. This resolution should make it possible to distinguish icebergs with a horizontal cross-sectional area of greater than $1{,}000m^2$ from ships and debris. In the present sample, slightly more than 50% of the icebergs and growlers are smaller than the $1{,}000m^2$.

Data collection will continue over the next several years to build an accurate base of information on iceberg sizes as a function of both season and geographic area.

REFERENCE

Murray, J. E., The Drift, Deterioration and Distribution of Icebergs in the North Atlantic Ocean (Ice Seminar: A Conference Sponsored by the Petroleum Society of CIM, Calgary, Alberta, May 1968.)

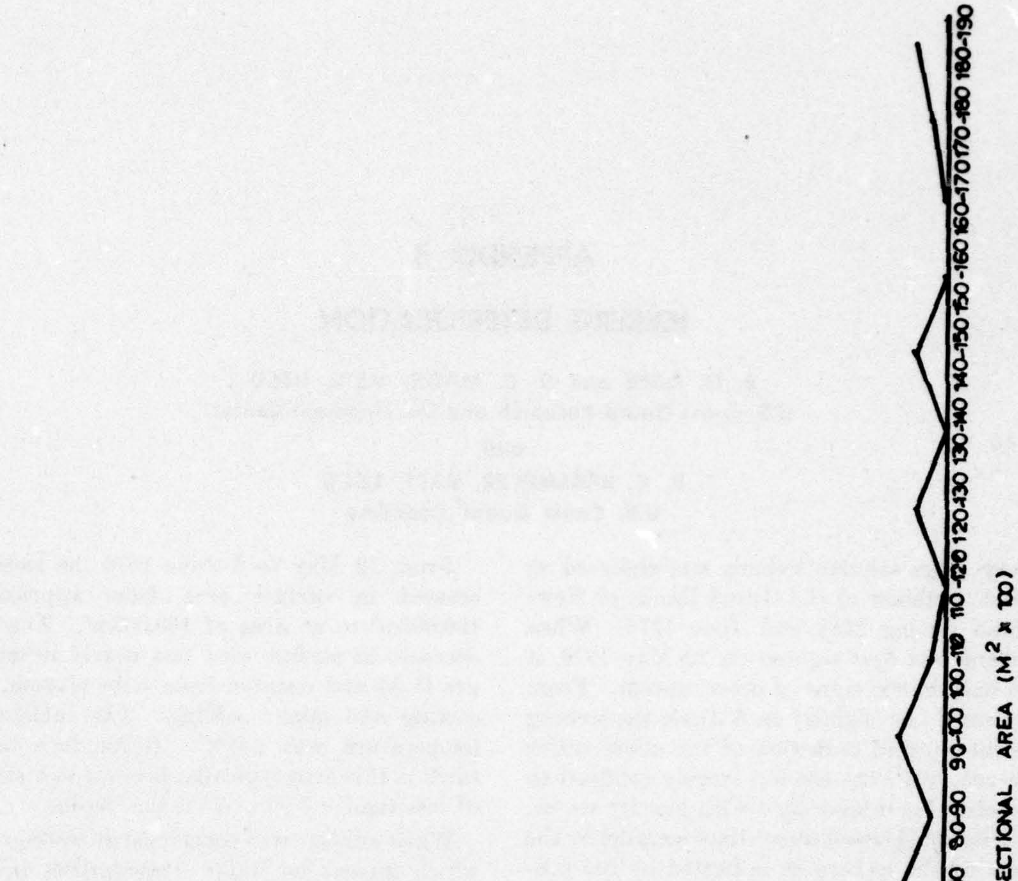


Figure A-1.—Size frequency distribution of icebergs, located in the vicinity of the Grand Banks of Newfoundland (1976).

APPENDIX B

ICEBERG DETERIORATION

R. Q. ROBE and D. C. MAIER, MST2, USCG
U.S. Coast Guard Research and Development Center
and
R. C. KOLLMEYER, CAPT, USCG
U.S. Coast Guard Academy

A very large tabular iceberg was observed as it drifted northeast of the Grand Banks of Newfoundland during May and June 1976. When the iceberg was first sighted on 12 May 1976, it showed only minor signs of deterioration. From 12 May until last sighted on 6 June, the iceberg underwent a rapid reduction of the above water surface area with the erosion largely confined to the turbulent layer associated with gravity waves. The erosion progressed along lines parallel to the structure of the iceberg as indicated by the pronounced ridge pair seen in the photographs (Figure B–1), a trellis drainage pattern, and an alternation of light and dark bands over the entire surface of the iceberg.

Photographs were taken of a large number of icebergs during the 1976 flights of the International Ice Patrol. These photographs are to be used for a study of iceberg populations off the Grand Banks (Figure B–2). Black and white photographs (9-inch format) were taken from altitudes of between 300 and 3500 m.

Among the photographs obtained are a unique series of five taken of the same iceberg over a period of 25 days (Figure B–1). It is highly unusual for an iceberg to be relocated over such an extended period when positive identification is possible. Icebergs normally change their appearance so radically by a combination of calving, melting and rolling, that it is impossible to positively identify them after only a few days. In this case the unusually low profile, only 4–5m of evaluation, and tabular shape maintained the iceberg in an extremely stable condition.

From 12 May to 6 June 1976 the iceberg decreased in surface area from approximately 190,000m^2 to an area of 109,000m^2. The rate of decrease in surface area was nearly linear (Figure B–3) and resulted from wave erosion, undercutting and minor calving. The surface water temperature was 2–4°C. Subsurface temperatures in this area typically decrease to a minimum of less than −1°C at 75–100m depth.

Wave erosion was concentrated at those points which appear as slight irregularities in the 12 May 1976 photograph. The progressive enlargement of these embayments was the result of the local concentration of wave energy and continued bathing of the ice by the turbulent water. The embayments seemed to extend only several meters below the water's surface and have an orientation parallel to the structural features of the iceberg. The underwater shape of the iceberg is not known but it is suspected to have had a flat bottom as inferred from the long-term maintenance of its top parallel to the sea surface.

The iceberg seemed to be of land ice origin. Analysis of a piece of the iceberg, recovered by the USCGC EVERGREEN, showed it to be fresh water ice. The characteristic air bubble bands of glacier ice were visible and surface melt tests produced a pattern of hexagonal depressions approximately 2cm across which typify the crystalline melt surface texture of glacier ice. The two linear parallel ridges in the upper third of each picture of Figure 1 are the most obvious manifestations of the ice structure. In the original photographic prints, a pattern of trellis drainage can be seen which indicates structural

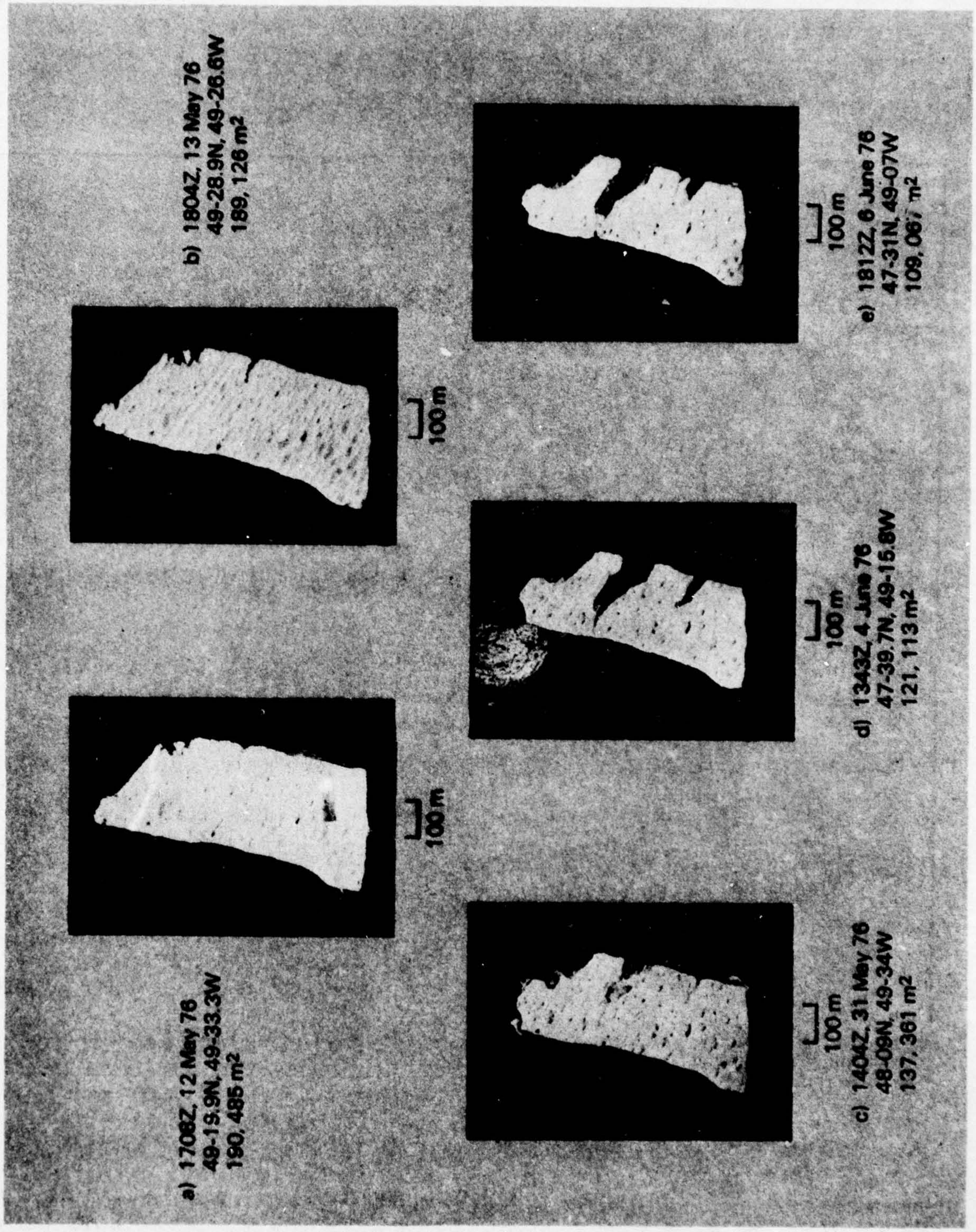


Figure B-1.—Time Series photographs showing the deterioration of an iceberg and the progressive enlargement of embayments.

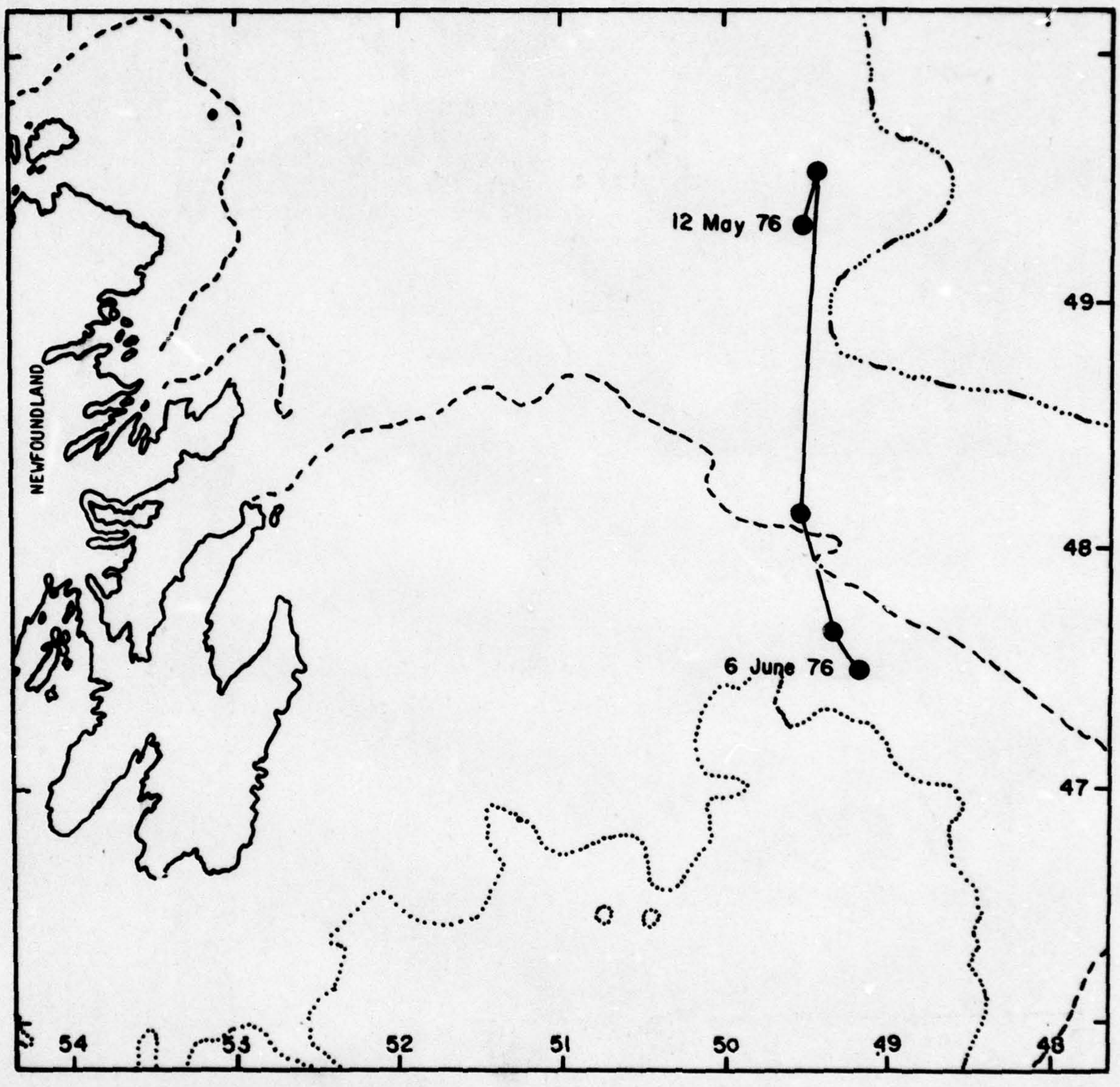


FIGURE B-2.—Drift Track of a large tabular iceberg near the Grand Banks of Newfoundland.

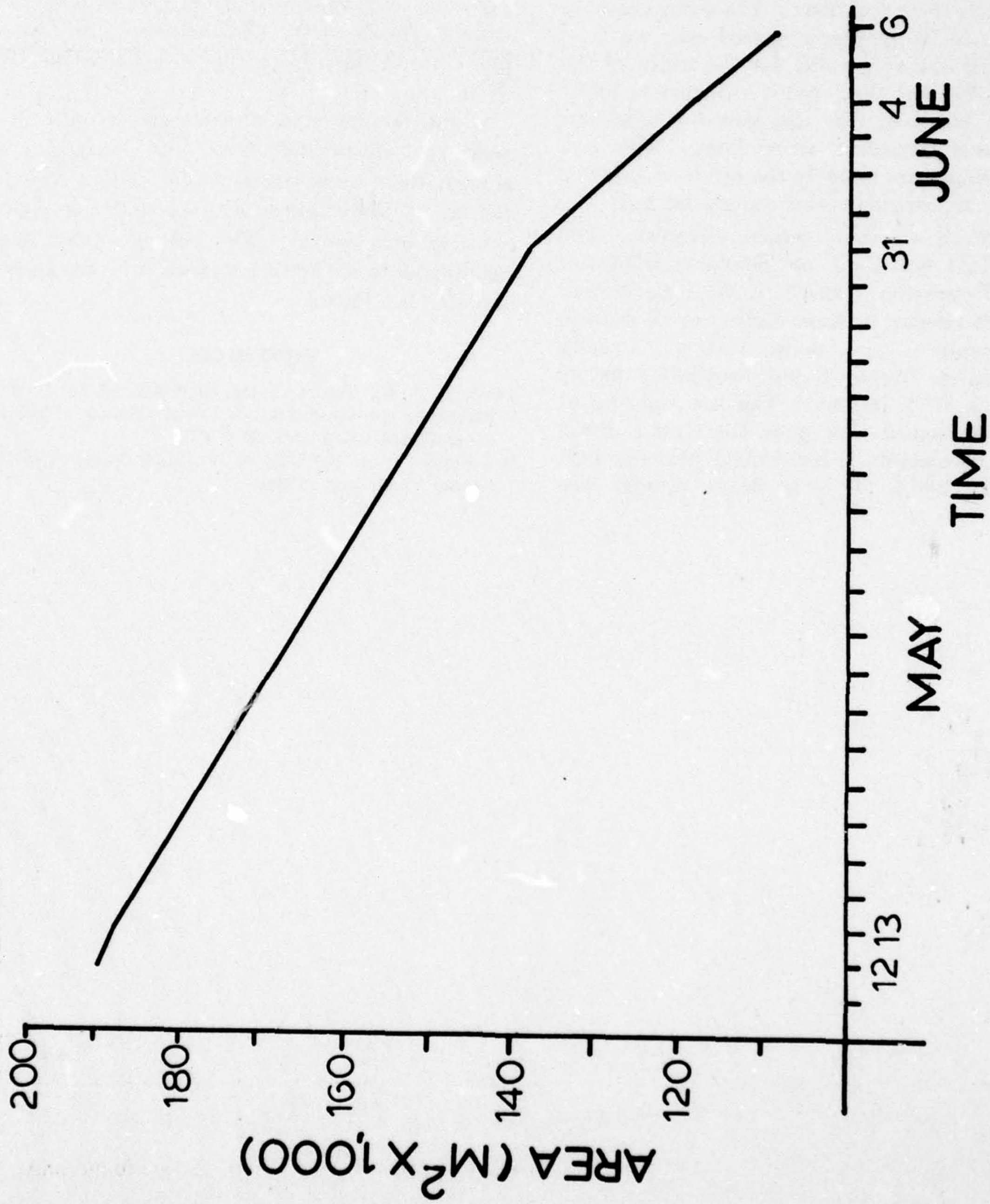


FIGURE B-3.—The reduction of the iceberg's sea level horizontal area as a function of time.

control. There is also an alternation of light and dark bands which while quite subtle are obvious on close examinations of an original photographic print. The banding is not a result of the drainage pattern since it is crossed by drainage channels in numerous locations. The band pairs do not seem to be regularly spaced nor are they perfectly linear or parallel for the width of the iceberg. We feel that such a structure is likely to be the result of flow and that the light and dark bands represent streamlines. The two parallel ridges are possibly the result of shear or flow over an irregularity of the glacial bed.

The iceberg's origin remains unknown. The Ward Hunt ice shelf on northern Ellesmere Island, Petermann Glacier in Hall Basin and Humboldt Glacier in Kane Basin are all capable of producing a thin tabular iceberg. Usually such icebergs fragment and deteriorate before they reach 50°N latitude. The last sighting of a similarly-shaped iceberg on the Grand Banks by the International Ice Patrol was in 1964 (Lenczyk, 1965). Twenty large tabular icebergs, some as long as 600m, were sighted by the Ice Patrol aircraft in late February of 1964 between Hamilton Inlet and Cape Chidley. They appeared as far south as 44°N by early May 1964. These icebergs were thought to have their origin in ice island WH-5 which was observed to block the Kennedy Channel from the Canadian shore to Hans Island in 1963 (Franceschetti, 1964).

A low tabular berg of this size is quite unusual and fortunately rare. It represents a greater than usual hazard for surface vessels due to its lower probability of detection, particularly in a seaway. The iceberg's uniqueness contributed to the attention given it by the International Ice Patrol.

REFERENCES

Lenczyk, R. E., Report of the International Ice Patrol Service in the North Atlantic Ocean (Season of 1964). Coast Guard Blletin No. 50 (1965).

Franceschetti, A. P., U.S. Coast Guard Oceanographic Report No. 5, 1-36 (1964).

APPENDIX C

WEST GREENLAND GLACIER SURVEY

R. C. KOLLMEYER, CAPT, USCG, Ph.D.
U.S. Coast Guard Academy

The statutory mission for the conduct of the International Ice Patrol provides for a study of ice and current conditions affecting the occurrence of icebergs in the North Atlantic Ocean. Commencing in 1914, the Coast Guard undertook a systematic series of oceanographic and ice studies. By 1928, these studies included the glacier origins of icebergs. Expeditions carried out by RADM E. H. SMITH between 1928 and 1935 identified twenty-one glaciers which make major contributions to iceberg occurrence in the North Atlantic Ocean. Average annual production rates for these glaciers were estimated and glacier front advance or retreat were determined qualitatively within the limits of available information.

The present ongoing West Greenland Glacier Survey was established in 1968. The intervening 33 years since SMITH's work left questions about changes and trends in the glaciers. The decades of the 1950's and 60's showed a decline in the mean number of icebergs drifting into the Grand Banks/Ice Patrol area. This was precipitous in comparison to the steady iceberg populations during the proceeding 50 years. Future planning and budgeting for International Ice Patrol, as well as planning for the possibility of greater arctic shipping obviously required a reinspection of the general productivity of the glaciers that produce the icebergs which hazard shipping. Trends during the first half of the 1970's turned out to be the reverse of the 50's and 60's. 1972 became the greatest year ever for icebergs on the Grand Banks and 1974 was the second greatest year on record. 1973, although not record breaking, saw two and one-half times the number of icebergs of a normal year. Conflicting interpretations of these data are obviously possible: advancing glaciers, abnormal meterorological conditions or a catastrophic breakup of the great floating ice tongues of West Greenland are all possibilities. Certainly, any of the above explanations can impact on the costs of operations for the Coast Guard. Glacial advance portends more ice and greater Coast Guard surveillance, and adversely affects the prospects of greater oil and mineral surface transport from the eastern Arctic. Glacial retreat, producing first a calving reduction, next a thinning of the floating ice tongues and then a rapid breakup, initially results in a declining population of icebergs followed by greatly increased numbers and then ultimately few.

In order to provide answers to the questions iterated above, the following objectives of the West Greenland Glacier Survey are being pursued:

1. Survey the West Greenland iceberg producing tidewater glaciers and compare the data thus obtained with earlier records to ascertain the advance of recession of the glaciers, future trends and changes in iceberg production rates.

2. Determine the annual number of icebergs calved from the major West Greenland glaciers and the regularity of production to determine the causes of annual number variation of icebergs found on the Grand Banks.

3. Survey environmental conditions affecting the calving and seaward drift of icebergs. This includes fjord configuration, sill depth and coastal circulation.

4. Provide a present pictorial and data documentation of the outlet glaciers of the last continental ice sheet in the Northern Hemisphere for future historical scientific use.

5. Provide the opportunity for invited glaciologists and polar scientists to participate in the

survey, contributing their knowledge and skills and conducting their own studies of Arctice regions not normally accessible to them.

An indirect benefit of the glacier surveys has been involvement of Coast Guard Academy cadets during the summer. Introduction of these cadets to arctic operations and icebreaking provide a source of interested and initiated Icebreaker officers.

The region of the West Greenland Glacier Survey is shown in Figure C-1. The first study, conducted in 1968, was staged from USCGC EASTWIND. The research group, headed by CAPT R. P. DINSMORE, surveyed the major glaciers from Jacobshavn (69°15′N Lat) to Northwest Bay. Jacobshavn is the southernmost glacier in the entire area of interest. In 1969, CAPT R. C. KOLLMEYER became the principal investigator and, using USCGC SOUTHWIND, surveyed between Upernivik and Kap York. Based on experience gained in 1968, detailed survey procedures, data gathering methods and photographic documentation commenced with this second study. The 1970 survey, conducted from USCGC WESTWIND, visited the glaciers from Kap York to Petermann Glacier in Hall Basin (81°30′N Lat), the northernmost glacier of the survey. Following this, the Coast Guard Academy took responsibility for the project with Captain KOLLMEYER remaining in charge. In 1971, the first in a series of planned revists was carried out, resurveying and photographing those glaciers visited in 1968. Due to ship schedules and mechanical problems, no additional surveys were conducted until the summer of 1976. At the time, USCGC WESTWIND supported a July survey conducting flow measurements of Jacobshavn Glacier, by now identified as the prime producer of icebergs threatening North Atlantic shipping. An automatic time-lapse motion picture camera viewed the terminus of the glacier in order to determine the regularity or irregularity of glacial movement. The camera was retrieved 18 days after its establishment and produced a remarkable record of glacier movement modes never before obtained. The 1968 and 1970 surveys were accompanied by a Coast Guard photomapping flight. High altitude stereo overlapping vertical photographs were obtained along the coastline from Jacobshavn Glacier north to the Humboldt Glacier.

The usual procedure for the survey of a glacier is as follows:

1. Conduct a helicopter flight to survey the region and select sites from which physical measurements of the glacier can be made.

2. After placing one or two survey parties ashore, locate the survey site by using visual landmarks and establish a metallic marker from which all data are referenced.

3. Optically survey the glacier terminus using a theodolite and laser rangefinder. Due to the size of some glaciers, triangulation is necessary from two different survey sites. The survey maps the shape and location of the calving terminus.

4. Measure optically the height of the calving terminus at as many points as possible. Measure floating tabular bergs when present.

5. Make observations concerning recently unglaciated or overrun terrain near the glacier. tidal markings on terminous, calving activity and freshness of the calving surface, iceberg population and fresh ice near the terminus, the presence of upwelled melt water immediately in front of the glacier, streaming zones and noise. Sketch the glacier.

6. Mark the survey site with a rock cairn to make it easily locatable in the future.

7. Photographically document the glacier from the survey site as well as the site itself and the surrounding terrain.

8. Complete a detailed photographic flight and document the glacier in accordance with the picture sequence shown on Figure C-2. (This is generally accomplished while the field parties are conducting the ground survey.)

9. Conduct oceanographic observations from the Icebreaker, including fjord soundings, sill depth determination and coastal and fjord water properties.

Variations in this procedure are often made depending on the glacier and the situation. Many minor glaciers are only photographed. To add to our knowledge, a number of coastal villages have been visited in order to obtain information on long-term ice trends observed by the residents.

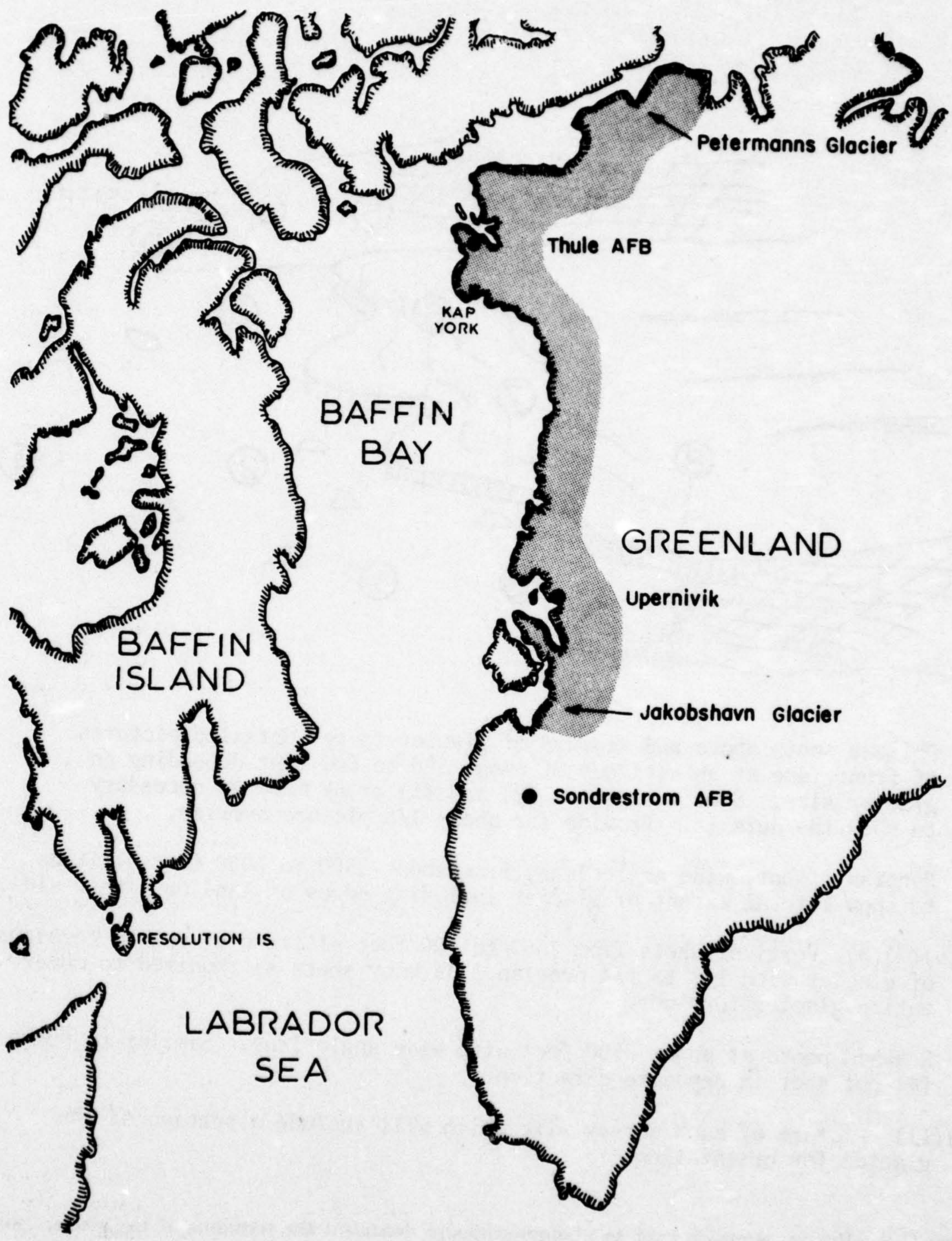
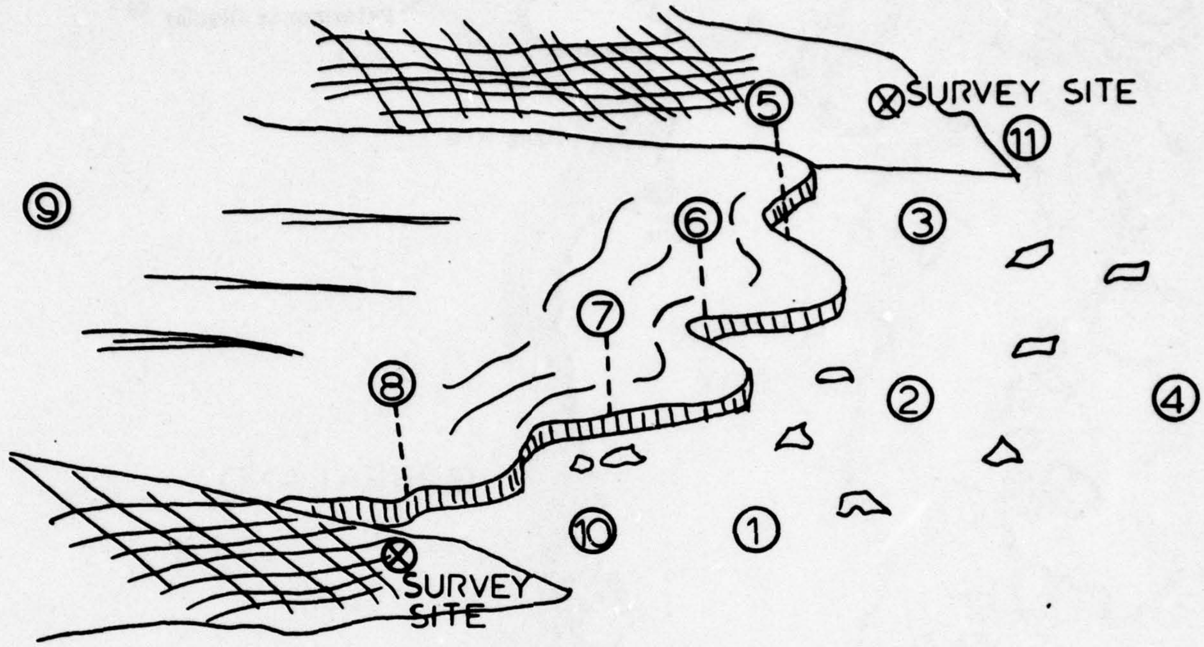


FIGURE C-1.—West Greenland Glacier survey area.



(1) Oblique shots above and seaward of glacier to get detailed pictures of front face at an altitude of about 500 to 800 feet depending on glacier size. Same for photos (2) and (3) or as many as necessary to show the details. Provide for about 1/8 picture overlap.

(4) Panoramic shot, wide angle lens, from about 2500 to 3000 feet altitude to show lateral extent of glacier including edges of land on either side.

(5)(6)(7)(8) Vertical shots from 2550 to 300 feet altitude of entire terminus of glacier with 1/8 to 1/4 overlap. As many shots as required to cover entire glacier terminus.

(9) Seaward photo at about 2500 feet with wide angle lens. Similar to number (4) but shot in opposite direction.

(10)(11) Picture of each survey site which will include a portion of the glacier for orientation.

Figure C-2.—Picture sequence used to photographically document the terminus of the glaciers surveyed.

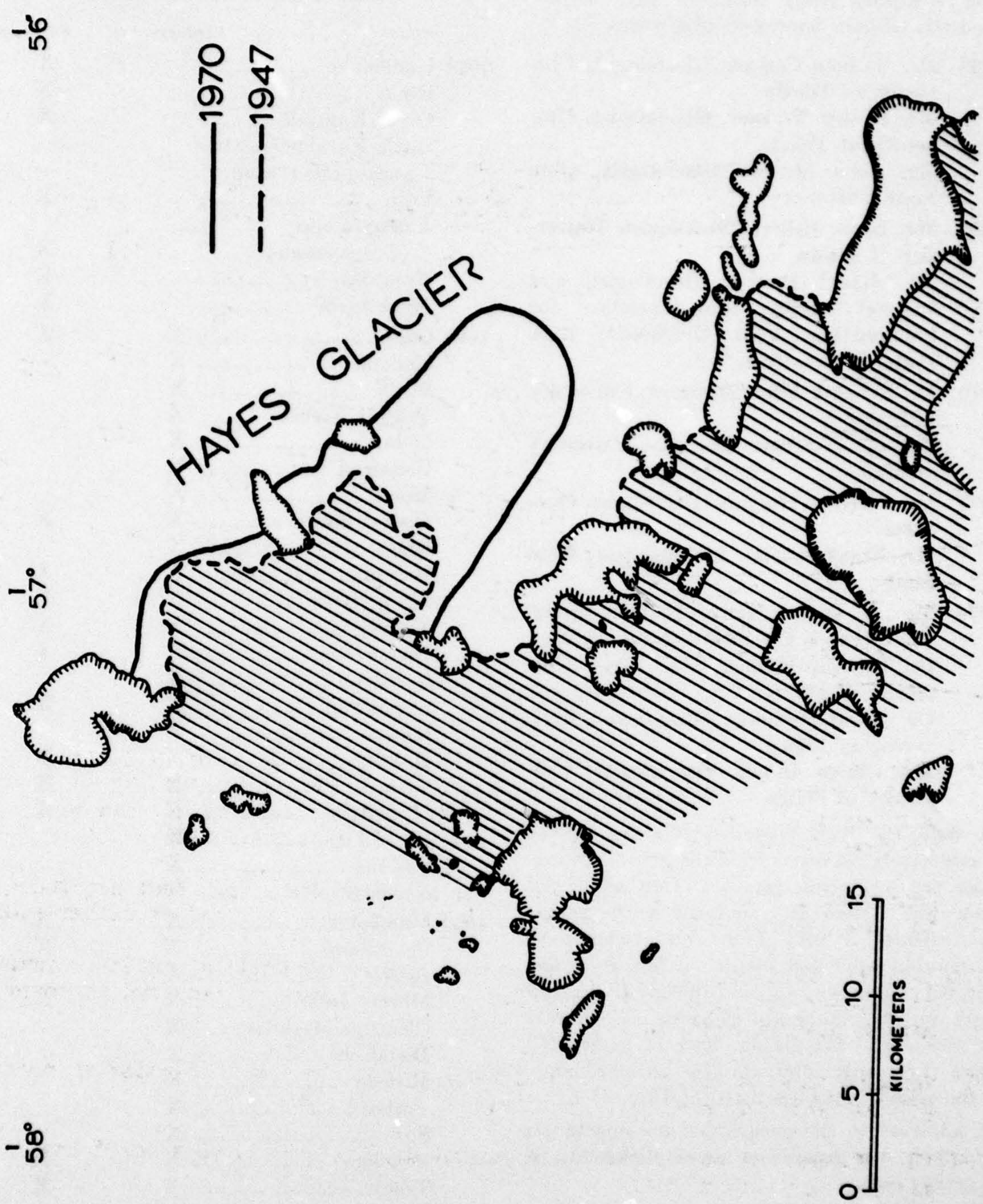


Figure C-3.—Terminus of Hayes Glacier as measured in 1947 and 1970. Shaded area denotes open water within fjord.

The following polar scientists have accompanied the Glacier Survey in past years.

1968 Dr. William Carlson, Glaciologist, University of Toledo
Mr. Dennis Trabant, Glaciologist, University of Toledo
Mr. John Mercer, Glaciologist, Ohio State University

1969 Mr. Louis Miller, Glaciologist, University of Alaska
Mr. David Potter, Glaciologist, and original survey team member for Sondrestrom AFB Greenland, 1940. Potter Instruments, N.J.

1970 Dr. Kenneth Allen, Zoologist, University of Maine
Dr. John Dearborn, Zoologist, University of Maine

1971 Dr. Terrence Hughes, Glaciologist, Ohio State
Mr. Frank Kuesel, Lichenologist, Ohio State

1976 Mr. R. Quincy Robe, Oceanographer, IIP research, CG R&D Center
Dr. Terrence Hughes, Glaciologist, University of Maine
Dr. Robert Thomas, Glaciologist, University of Maine
Mr. Craige Lingle, Glaciologist, University of Maine

To date, the West Greenland Glacier Survey has extensively surveyed from the ground 26 major iceberg producing glaciers. One additional glacier was visited and surveyed with sextant measurements. A total of 59 outlet glaciers have been photo-documented with color film from low flying helicopters and the entire West Greenland coastal region photographed twice by aircraft from 8000 feet. Six glaciers have been revisited after a three year interval. The glacier names and the years visited are listed in Table C–1.

In addition to the geographic documentation cited above, the significant accomplishments of this survey are:

1. Through comparisons of present surveys with historical data, a general retreat of the tidewater glaciers of West Greenland is documented. Some glaciers have retreated as much as 13 kilometers in 22 years as shown by the changes in Hayes Glacier, Figure C–3, to cite one example.

TABLE C–1—GLACIERS VISITED

	Glacier	*Photographed*	*Surveyed*
1968	Umiamako		X
	Rinks		X
	Great Karajak		X
	Little Karajak—sextant angles/observation		—
	Eqip		X
	Avangnarelleq (Torssukatak)		X
	Kujatdleq		X
	Jacobshavn		X
1969	Gade	X	X
	Helland	X	
	Wulff	X	
	Yngvar Nielson	X	
	Mohn	X	
	Unnamed !	X	
	Morell	X	
	Docker Smith	X	X
	Rinks	X	
	Pearys	X	X
	Kong Oscar	X	X
	Nansen	X	X
	Dietrichson	X	X
	Sverdrup	X	
	Steenstrup	X	X
	Kjears	X	
	Hayes	X	X
	Giesecke	X	X
	Upernivik	X	X
	Cornell	X	
	Ussings	X	
	Nordenskiolds	X	
1970	Humboldt	X	X
	Petermann	X	X
	Bissels	X	
	Morris Jesup	X	X
	Clements Markham	X	
	Diebitsch	X	
	Meehan	X	
	Verhoeff	X	
	Sun	X	
	Bowdoin	X	X
	Tracy	X	X
1970	Heilprin	X	X
	Farquaar	X	
	Academy (Leidy)	X	X
	Petowik (Pitugfix)	X	X
	Sermerssuaq (Moltke)	X	X
	Knud Rassmussan	X	

Glacier	Photographed	Surveyed
Agpat	X	
Hart	X	
Sharp	X	
Melville	X	
Savage	X	
Berlingske	X	
Hurlbut	X	
Chamberlin	X	
Brother Johns	X	
Dodge	X	
San Martin	X	
Hubbard	X	
Marre	X	
Unnamed!	X	
1971 (Glaciers from 1968 expedition resurveyed)		
Jacobshavn	X	X
Rinks	X	X
Uniamako	X	X
Great Karajak	X	X
Avangnarelleq (Torssukatak)	X	X
Kujatdleq	X	X

2. Redefinition of those glaciers considered major iceberg producers by RADM E. H. SMITH. Several that he felt contributed to the ice patrol problem are now grounded and not producing icebergs. Others, never visited by SMITH, have been added to the major producer list.

3. Determination of floating glacier elevations with over 120 measurements of height made. A significant contribution since floating ice terminus elevation data are virtually nonexistent in the literature.

4. Tidal measurements and a number of horizontal movement vectors were determined for Jacobshavn Glacier. On two different visits, velocities of up to 21 meters per day were obtained by optical observations. This is the fastest movement ever detected in a steady flowing glacier.

5. Time lapse motion pictures of Jacobshavn Glacier obtained over 18 days. These pictures disclose the glacier's flow movement to be surprisingly, steady, river like in manner.

6. Iceberg volume production estimates have been computed for Jacobshavn Glacier showing an annual production of 27.6 cubic kilometers of ice. This is about 10% of the total iceberg volume produced by all of West Greenland.

7. Homboldt Glacier, all 60 nautical miles of its terminus, was surveyed from the ground using both land pin points and NAVSAT navigation for seaward measurements. This survey of the terminus location of the largest glacier in the northern hemisphere had never been accomplished before. One interesting finding is that with all the prodigeous potential for iceberg production, successive year aerial surveys showed the same iceberg sitting in place, grounded and obviously not part of the major supply of icebergs to the Grand Banks region. The Explorers Club of New York sent Explorer Club flag number 193 which was flown over the survey sites during this first time survey of the Humboldt (1970).

8. Petermann Glacier, 81°30'N, originally observed during the ill-fated Hall-Polaris expedition of 1871–73, was found in 1970 to be a badly wasted, low profile floating ice tongue with no iceberg production. It was surveyed and described in 1872 as "a confused accumulation of bergs, crowded closely together, leaving such spaces only as were due to irregularities of form". Petermann fjord was full of icebergs then and those icebergs could have come only from Petermann Glacier. Hall's ship, the Polaris, wintered over there while moored to a giant iceberg. In 1970, there were no icebergs nor a possible source of icebergs within 100 miles of Petermann fjord.

9. The development of "in-house" expertise in the field of glaciology by Captain KOLLMEYER through text book and journal studies over the last eight years and on-site glacial work during the survey expeditions. This includes the development of several techniques of marking glaciers to allow optical measurements of movement to be performed both from the surface and through the use of aerial photography. This expertise within the Coast Guard has been recently expanded because of the involvement of LCDR Howard B. GEHRING, USCG and R. Quincy ROBE, IIP Research, Coast Guard R&D Center, in the 1976 survey expedition.

With the data already obtained by the West Greenland Glacier Survey, objectives 3 and 4 above have been accomplished. Objective 5 should be a continuing program for visiting scientists as long as the survey is pursued and space on the Icebreaker is available. Objective 1 has been accomplished with the exception of

definition of trends. Resurvey of certain glaciers could better establish these trends. Objective 2, completed for Jacobshavn Glacier, can also be accomplished for the other major producers by resurvey where the time spent at each glacier is basically devoted to measurements of glacier movement. Thus, future plans for the West Greenland Glacier Survey call for continuing the resurvey program of the major iceberg producing glaciers to obtain verification data and to detect the continuance of the recession trends. Site reoccupation would include both tidal flexure measurements and short-term flow velocity determinations. These data will allow iceberg production calculations. A total of three more survey expeditions, visiting only the most productive glaciers, would be required. In addition, a program of ERTS Satellite monitoring of the glaciers will be commenced. As satellite technology improves, all iceberg production and glacier retreat monitoring will be accomplished remotely and at comparatively little expense.

The quantity of photographs and recorded data obtained since 1968 is large. The Glacier Survey has very thorough documentation of the glaciers of West Greenland. This information would be quite useful as a reference resource to glaciologists, oceanographers, climatologists and geographers. Historically, these data are an important benchmark in the geophysical studies of the earth. I hope they will be published and made available in the most complete and definitive form possible, with a complete narrative, data measurements, calculations and color photographs, with the photographs being of prime importance.

APPENDIX D

OPERATIONAL USE OF FREE-DRIFTING, SATELLITE-TRACKED BUOYS

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U.S. Coast Guard Oceanographic Unit

The 1976 Ice Patrol season initiated the Coast Guard's use of the Buoy Transmitting Terminal (BTT) buoy system. This system is capable of drifting with the ocean currents and transmitting information via satellite. The information is then relayed to ground stations where environmental data and buoy position are determined. A BTT buoy, called the Conshelf Drifter, is shown in figure D-1. This buoy is manufactured by Polar Research Labs of Santa Barbara, California. The buoy used in 1976 was manufactured by NOVA University, Fort Lauderdale, Florida and was very similar in shape and design. A window shade drogue 13 meters long and 2 meters wide was used to increase water drag. A full description of this type of drogue is contained in Vachon (1975).

The position fixing capability and the transmission of environmental data are accomplished through the use of the Nimbus-6 Satellite Random Access Memory System (RAMS). The technical specifications are given by Sissala (1975). Basically, the BTT buoy broadcasts a frequency stabilized UHF signal for 1 second every minute regardless of whether or not the buoy is within sight of the satellite. Contained within this signal is a platform identification number and four eight-digit words. During a satellite pass the spacecraft receives this information and accurately determines the frequency at which it was received. The doppler shift information is used to determine the buoy's position.

The buoy used in 1976, platform I.D. 0177, was deployed on 4 April in position 46°59.2′N, 47°15.1′W along standard section A-2. Excellent data were received through 13 April. During this time 5 to 11 positions were obtained every day. On 11 April a storm moved the buoy westward and up onto the Grand Banks. The depth in this area decreases to 100 meters or less and may have interfered with the drogue. After 13 April the buoy experienced an intermittent electronic failure and positions were obtained only on the days shown in figures D-2 and D-3. These figures show the BTT movement relative to general ocean currents. The last transmission from the buoy was on 15 September 1976. A detailed analysis of the data that were obtained from this system will be the subject of a separate report.

The data from the buoy yielded three important results. The first was the buoy's apparent response to wind currents. On April 4th, 5th and 6th the buoy drifted northwest and not southwest as indicated by the dynamic topography. During this same period the wind was from the southeast at speeds up to 35 knots. The second interim finding was that the buoy's drift direction during periods when the wind was less than 20 knots closely followed the dynamic topography. The third result was that during the period of moderate winds the buoy moved along the edge of the Labrador Current at an average speed of about 30 cm/sec. The dynamic topography of a survey taken just previous to this experiment gives an average speed of about 25 cm/sec.

These three results have a major impact on iceberg drift and they further confirm our previously held beliefs; that is, wind generated currents must be considered when determining iceberg drift, that dynamic topography is quite accurate in determining the baroclinic component of the current direction, and that dynamic topography produces a current speed that is too conservative.

REFERENCES

Vachon, William A. 1975. Instrumented Full-scale Tests of a Drifting Buoy and Drogue, Charles Stark Draper Laboratory, Inc., R-947.

Sissala, J. E. 1975. The Nimbus 6 Users Guide. Available from LANDSAT/Nimbus Project, Goddard Space Flight Center, Greenbelt, MD.

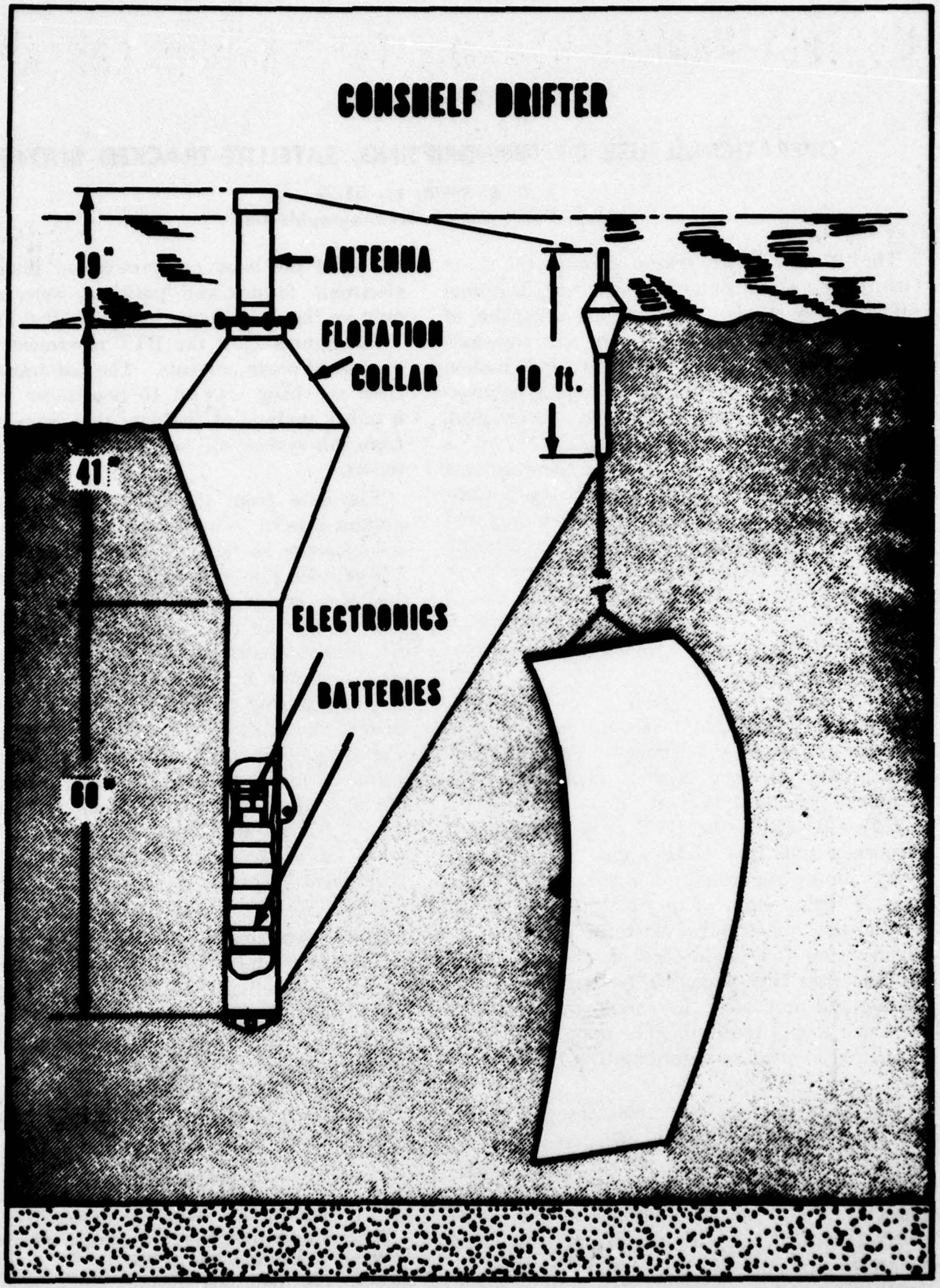

FIGURE D-1.—BTT buoy design.

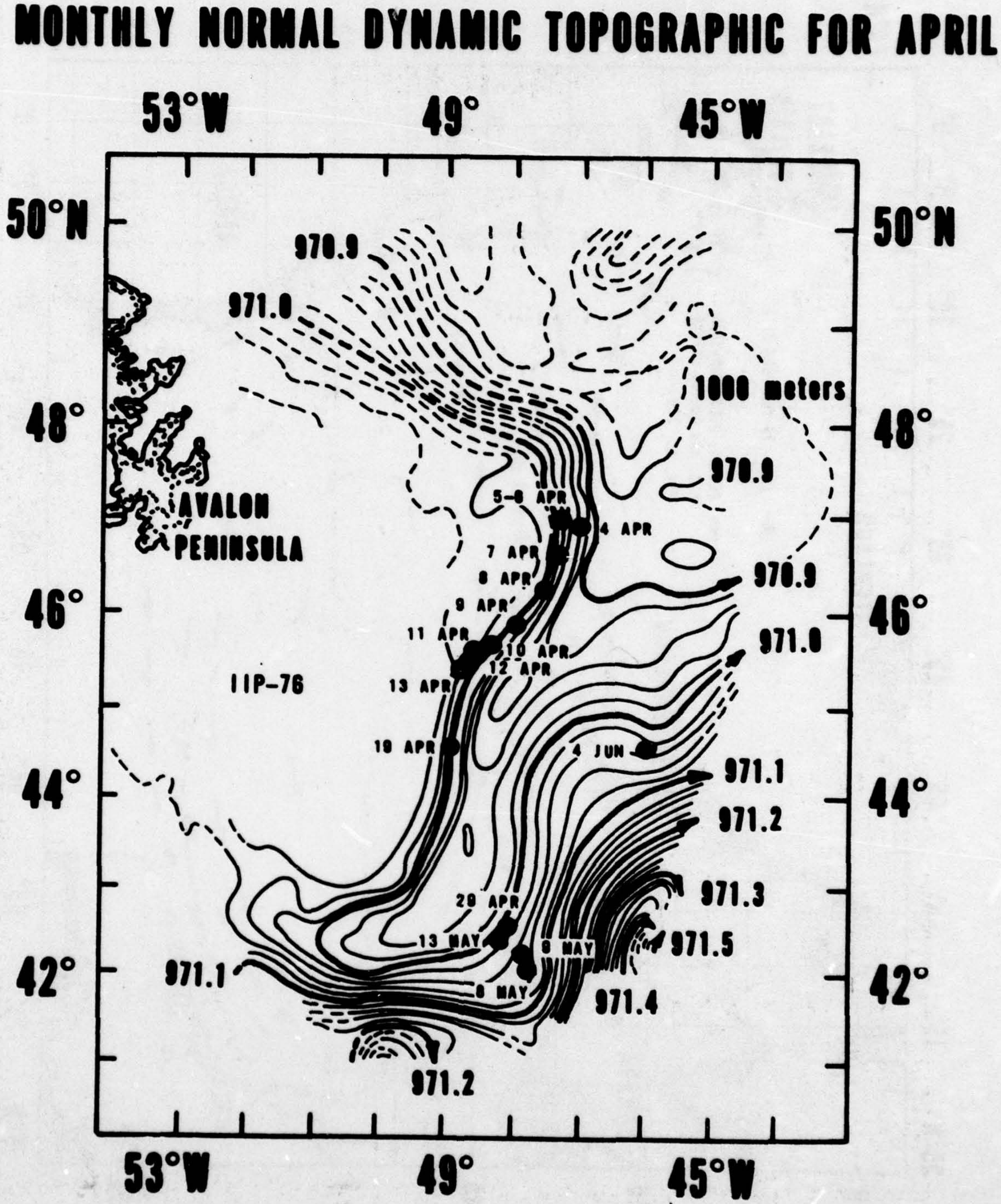

FIGURE D-2.—Drift of BTT buoy within the IIP area (I.D. 0177).

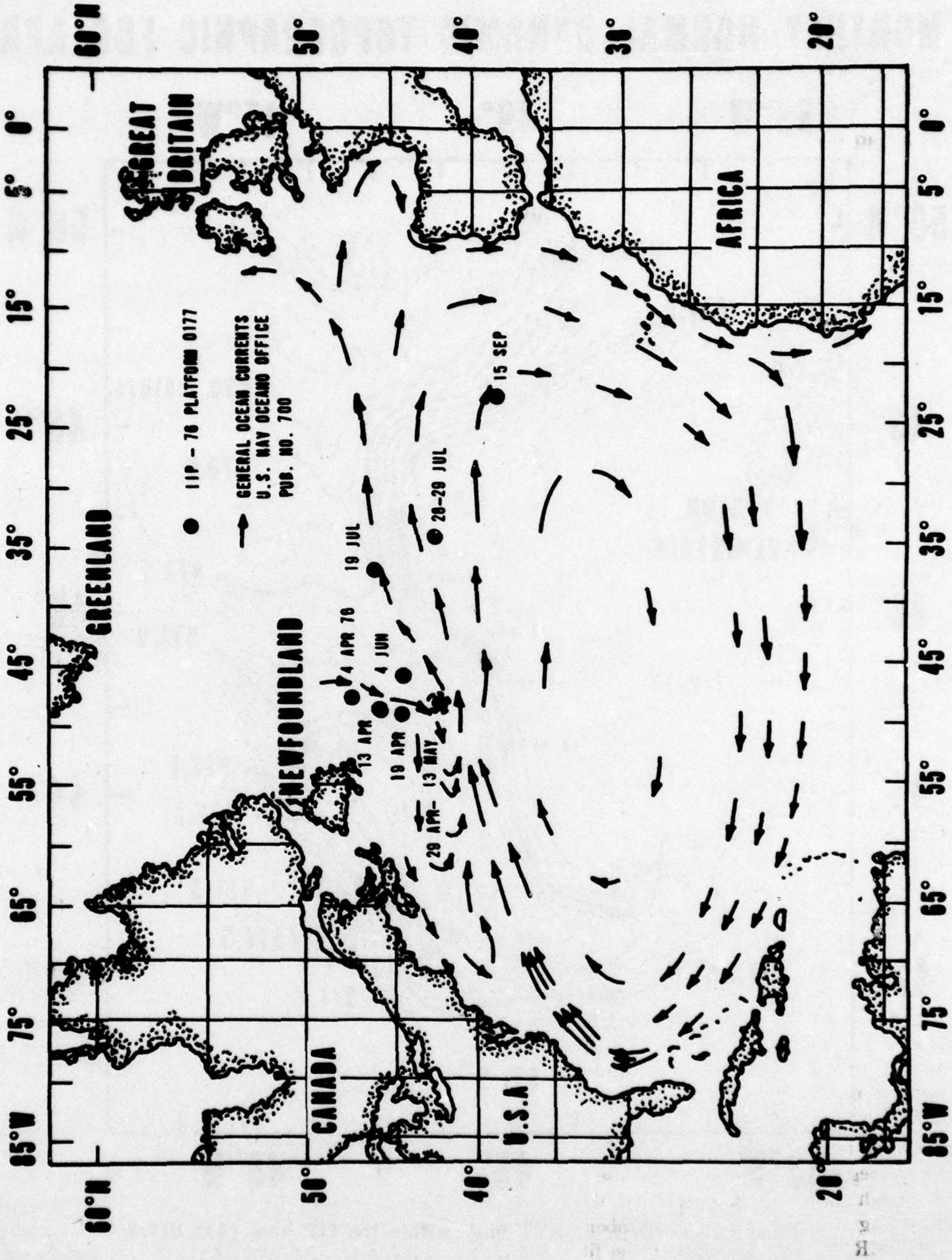

Figure D-3.—Drift of BTT buoy from 4 April to 15 September 1977 (I.D. 0177).

APPENDIX E

OBSERVATIONS OF SEA SURFACE TEMPERATURES IN THE VICINITY OF THE GRAND BANKS

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Staff Oceanographer
International Ice Patrol

The International Ice Patrol has an operational need for reliable, accurate sea surface temperature (SST) data in the vicinity of the Grand Banks to be used in the prediction of iceberg deterioration rates and definition of certain ocean current regimes. The Grand Banks offers one of the most dynamically active ocean areas in the world with the cold, narrow Labrador Current meeting the warm North Atlantic Current. This situation, complicated by the fact that both currents constantly vary in magnitude and position, account for relatively rapid changes in oceanographic features, including SST. To maintain a useful plot of SST data, frequent updates are needed. Ice Patrol presently receives SST reports from merchant vessels transiting the area, hourly from the Ice Patrol Oceanographic Research Vessel (USCGC EVERGREEN) when in the vicinity of the Grand Banks, from airborne radiation thermometer (ART) surveys conducted on routine ice reconnaissance flights and from satellite infrared imagery.

Due to the remoteness of the Grand Banks area, ship reports are infrequent. Even with U.S. Coast Guard Oceanographic Cutter EVERGREEN reporting hourly SST's, vessels alone cannot provide the coverage and density of samples necessary to develop the SST contours needed by Ice Patrol.

In the latter part of the 1974 Ice Season, Ice Patrol began its first operational use of the ART. Although IIP had experimented with infrared recording devices for a number of years (OSMER, 1974), this marked the first time the ART had been used operationally on the Grand Banks. The first recorded use of an infrared device for measuring water temperatures from an aircraft was by Woods Hole Oceanographic Institute in surveying the Gulf Stream (STOMMEL et al, 1953). They found that an airborne infrared detector was capable of providing a chart of surface thermal gradients over a much greater area than could be covered by surface vessels, and in a much shorter time. Continuing research using the Stommel-Parsons instrument, they developed a series of thermal gradient charts that defined the fine structure of the Gulf Stream front (VON ARX et al, 1955). With the potential value of the instrument determined, its use became more widespread.

Using a more sensitive instrument manufactured by the Barnes Engineering Company, Richardson and Wilkens (1958) reported the existence of certain errors in sea surface radiation measurements from aircraft. These appeared to result primarily from the reflection of solar radiation from the sea surface and the atmospheric conditions at the time of recording. The atmospheric errors were due to radiation absorption by atmospheric water vapor in the 5 to 7 micrometer band, and by carbon dioxide in the 14 to 16 micrometer band; thus the 8 to 13 micrometer window was found to be most useful for infrared remote sensing (KETCHEN et al, 1977).

International Ice Patrol has been using the Barnes PRT–5 for ART surveys, operating with a 9.5 to 11.5 micrometer window while flying at altitudes of 1000 feet or lower. Even with this window, any appreciable amount of water vapor in the air column between the aircraft and the water surface (including light fog, thin cloud cover and water spray from strong surface

winds) has been found to have a significant effect on the accuracy of the ART record. This fact has prohibited the effective use of the ART during roughly 40% of the reconnaissance missions flown by the Ice Patrol.

The Center for Cold Ocean Resources Engineering (C-CORE) at Memorial University of Newfoundland in St. John's has recently tested two techniques for applying correction factors to account for atmospheric attenuation. Although not presently using either of these techniques, IIP is considering their use for improving the absolute accuracy of the ART surveys. In these methods, an emissivity value of almost unity is assumed for water; thus, no emissivity correction is contained in either procedure.

Pickett Method

This technique uses an empirically derived correction equation that uses multiple regression (EFROYMSON, 1964). Environmental variables considered in the derivation were altitude, altitude squared, square root of altitude, air temperature squared, square root of air temperature, the difference between air temperature, and ship bucket temperature (PICKETT, 1966). Pickett used these variables because they could be easily and accurately measured. He did not take into consideration humidity effects. Using correlation coefficients between the ART error and the environmental variables, Pickett determined that altitude and air temperature were the two most important variables. From his results the following empirical environmental correction equation was determined:

$$C = 1.54 + 0.00046A - 0.043T,$$

where, C = environmental correction to be added to the ART value (°C)

A = altitude in feet, and

T = air temperature at 1,000 feet (°C).

Pickett devised a chart for quick determination of the correction for the radiation temperature that compares that altitude (feet) versus air temperature at flight level.

Atmospheric Environment Service Method

This method evolved from a computer procedure that was used to correct Richards' (1966) data (SHAW, 1966). Shaw and Irbe (1972) and Irbe (1972) have described a graphical method that required knowledge of the vertical distribution of temperature and humidity in the vicinity of the aircraft. They felt that corrections for the air column above 2,000 feet were unnecessary, and that the correction using the graphical means was comparable to the measurement error of the recording instrument (±0.5C°) specifications. They found that an overcast cloud layer increased the ART reading by 0.5C° above the values for clear sky. Irbe (1969) found that the atmospheric correction was of utmost importance for reducing data if unusual surface water temperature patterns were to be discerned and Shaw and Irbe (1972) felt that the instrument could be extremely useful in monitoring surface water temperatures near freezing.

The correction technique involves the determination of instrument drift over the flight period using inflight calibration; the plotting of an environmental correction graph which is a plot of the ART temperature with drift corrections versus the measured surface water temperature; and the application of a correction factor for errors due to the water vapour mass under the aircraft. The water vapour data were recorded from independent information available from the nearest upper air meteorological station. Irbe (1972) contains the required graphs for carrying out the corrections. This technique replaced the computer method of Shaw (1966), and has proven satisfactory for the AES program.

Of the two correction methods, the AES correction is preferred because it attempts to account for changes in temperature and humidity of the air column under the aircraft. This correction is also sensitive to changes from clear to overcast skies. The Pickett method is very insensitive to altitude changes and outside air temperature and makes no allowances for humidity. The Pickett method was normally 2°C for most of the Ice Patrol Grand Banks surveys in 1976, regardless of atmospheric conditions.

To implement the AES method, accurate outside air temperature and humidity at altitude should be collected at the same time as ART information. This requires an accurate outside air temperature sensor and an airborne hygrometer. Accurate navigational information is available from Ice Patrol aircraft's inertial navigation system, as are altitude readings. Cloud cover could be monitored by the ice observer during the flight.

Surface radiation measurements are also available from satellite sensors. Unfortunately, the imagery provided from satellites presents only varying shades of gray with the warmer waters showing up as dark areas and cold as light gray to white. No absolute values of temperature are assigned to these shades. ART and ship SST data can be used to calibrate the imagery. Temperature contours can then be drawn over the entire area covered by the usable portions of the image (i.e., those not obscured by cloud or fog cover). The obvious advantage of this system is its ability to provide synoptic coverage over a wide area.

Figure E-1 is a satellite IR image of the Northwest Atlantic Ocean oriented with North toward the upper left corner. Point (7) marks position 46°05′N, 45°25′W. Scattered cloud cover can be seen in the lower right half of the photo and over the Grand Banks to the north. Some of the more pronounced temperature gradients have been marked on the image. Figure E-2 is an interpretation of this imagery, calibrated from SST reports received on that date. Figure E-3 was developed totally from ship SST reports received between 3 and 9 May, 1976. ART contours from surveys conducted on 30 April, 1, 5 and 6 May are depicted in Figure E-4. Although there are certainly similarities between all three contours (Figures E-2, E-3 and E-4), some differences are quite obvious. These differences are due to the lack of synopticity and the need to perform interpretative contouring between data points or lines in both figures E-3 and E-4. The satellite imagery provide a much better definition of the surface temperature gradients.

REFERENCES

Efroymson, M. A., "Multiple Regression Analysis" *Mathematical Methods for Digital Computers*, Edited by A. Ralston and H. Wilf, Wiley and Sons, New York, 1964.

Irbe, J. G., "Some Unusual Surface Water Temperature Patterns In The Great Lakes, As Detected By Airborne Radiation Thermometer Surveys", *Proc. 12th Conf, Great Lakes Res.*, Internat. Assoc. Great Lakes.

Ketchen, H. G., LaViolette, P. E., and Worsfold, R. D., "Thermal Studies of the Grand Banks Gulf Stream Slope Using Airborne Radiation Thermometers and Satellite Data", *Proc. Fourth Canadian Symposium on Remote Sensing*, Quebec City, p. 163–175, 1977.

Irbe, J. G., "Aerial Surveys of Great Lakes Water Temperatures April 1968 to March 1970" *Climatological Studies No. 19*, Environment Canada, 1972.

Pickett, R. L., "Environmental Corrections For An Airborne Radiation Thermometer: *Proceedings of the Fourth Symposium on Remote Sensing of Environment*, p. 259–262, April, 1966.

Richards, T. L., "Great Lakes Water Temperature By Aerial Survey", *Extract of Publication No. 70 of the I.A.S.H. Symposium of GARDA*, pp. 406–419, 1966.

Richardson, William S., and Wilkins, Charles H., "An Airborne Radiation Thermometer", *Deep-Sea Research, Vol. 5*, p. 62 to 71, Pergamon Press Ltd., London, 1958.

Shaw, R. W., "Environmental Errors In The Use of The Airborne Radiation Thermometer", *M.A. Thesis*, University of Toronto, 1966.

Shaw, R. W., and Irbe, J. G., "Environmental Adjustments For The Airborne Radiation Thermometer Measuring Water Surface Temperature", *Water Resources Research, Vol. 8, No. 5*, p. 1214 to 1225, 1972.

Stommel, Henry, Von Arx, W. S., Parson, D., Richardson, W. S., "Rapid Aerial Survey of Gulf with Camera and Radiation Thermometer", Sciences 117, p. 639–640, 1953.

Von Arx, W. S., Bumpus, D. F., and Richardson, W. S., "On the Fine Structure of the Gulf Stream Front", Deep-Sea Research, Vol. 3, p. 46 to 55, Pergamon Press Ltd., London, 1955.

FIGURE E–1.—Thermal Infrared Imagery recorded by a NOAA satellite, May 6, 1976.

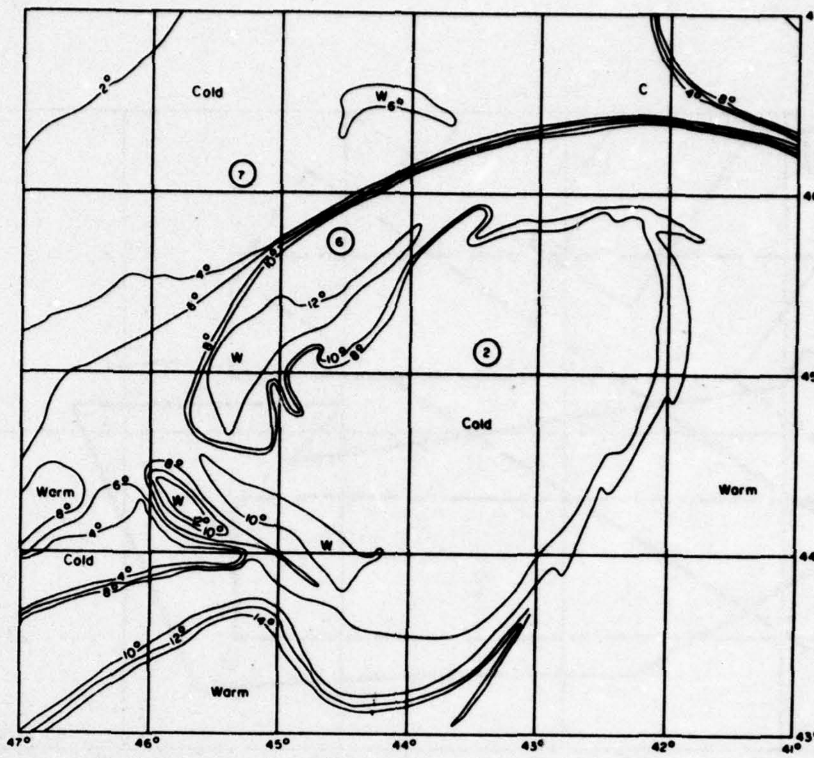

FIGURE E-2.—Interpretation of satellite infrared imagery, May 6, 1976 (°C).

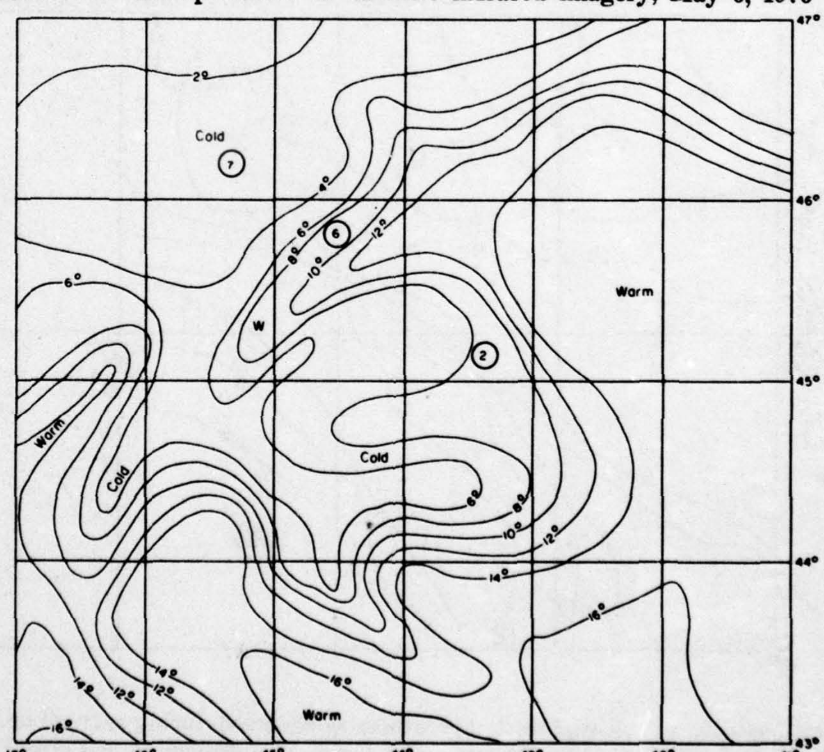

FIGURE E-3.—Sea Surface Temperature Contours developed from ship observations between 3 and 9 May 1976 (°C).

FIGURE E-4.—ART contours of sea surface temperatures as observed during surveys on 30 April and 1, 5 and 6 May, 1976 (°C). Surveys did not cover entire area shown in Figures E-2 and E-3. The top figure shows flight tracks flown during the surveys.

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